Regional Spinal Kinematics and Muscle Activity in Non-Specific Chronic Low Back Pain during Functional Tasks: Evaluation of a Sub-classification Approach

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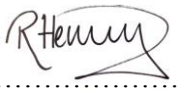
Signed  Date: 30/09/2015

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Abstract

Background:

Differences in regional lumbar angles in sitting have been observed between subclassified groups of NSCLBP patients. However, differences during standing posture, range of movement and functional tasks, as well as differences in thoracic kinematics, have not been explored to date, despite classification-based cognitive functional therapy (CB-CFT) approaches being proposed to be effective for these subgroups.

Methods:

Spinal kinematics and trunk muscle activity of 27 Flexion Pattern (FP), 23 Active Extension Pattern (AEP) and 28 healthy controls were recorded (using 3D motion analysis (Vicon®) and surface electromyography) during: usual sitting, usual standing, flexion, extension, sit-to-stand -to-sit, reach up, stepping up and down, lifting and replacing a box and bending (and return) to pick up a pen tasks. Midpoint regional sagittal spinal angles and normalised amplitude sEMG for trunk muscles bilaterally were compared between groups. Statistical analysis was conducted using one-way ANOVAs (kinematics) and Kruskal-Wallis (muscle activity) tests.

Results:

Significant differences were observed between the AEP and FP groups in the upper lumber and lower thoracic spine during most postures and tasks. Some significant differences were also observed between the FP and control groups in these regions. Additionally, significant differences in the total lumbar spine between AEP and FP groups were occasionally evident. No differences in any other spinal region (or between AEP and control groups) were observed. Some significant differences ($p<0.05$) in unilateral muscle activity were also observed between the NSCLBP and healthy control groups.

Conclusion:

The study findings further validate the classification approach (O'Sullivan, 2005). It highlighted that kinematic differences were observed to consistently occur in the thoraco-lumbar region during both static postures and functional tasks. Sub-division of regional spinal angles is key to identifying sub-group differences. These findings can inform novel CB-CFT interventions and highlights the need for targeted thoraco-lumbar spinal movement re-education strategies in NSCLBP subgroups.

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This thesis is dedicated to Alan Hemming.
A great believer in learning who always supported us to pursue an education he could have only ever dreamed of.

Publications and Presentations

Abstract Publications

Hemming, R., Sheeran, L., van Deursen, R. and Sparkes ,V. (2015) Regional spinal kinematics during static postures and functional tasks in people with non-specific chronic low back pain *International Journal of Therapy and Rehabilitation* 22(8) (Suppl. S8)

Hemming, R., Sheeran, L., van Deursen, R. and Sparkes,V. (2015). Regional spinal kinematics during static postures: discrimination between subclassified people with non-specific chronic low back pain (NSCLBP) and healthy controls *Bone & Joint Journal* 97-B (Suppl. 2, p.17).

Sheeran, L., Hemming, R., and Sparkes, V. (2014) Classification-based cognitive functional group therapy (CB-CFT) in patients with non-specific chronic low back pain (NSCLBP) *Bone & Joint Journal* 96-B (Suppl. 4, p35)

Conference Abstracts

Regional Spinal Kinematics during Static Postures and Functional Tasks: Discrimination between Sub-Classified People with Non-Specific Chronic Low Back Pain (NSCLBP) and Healthy Controls
R Hemming, L Sheeran, R van Deursen, V Sparkes
3rd South West Regional Regenerative Medicine Meeting, November 2015 (Podium presentation)

Evaluating sagittal spinal posture during functional tasks: can kinematics differentiate between non-specific chronic low back pain (NSCLBP) subgroups and healthy controls?
R Hemming, L Sheeran, R van Deursen, V Sparkes
EuroSpine 2015, Copenhagen, September 2015 (e-poster presentation)

Regional Spinal Kinematics during Static Postures and Functional Tasks: Discrimination between Sub-Classified People with Non-Specific Chronic Low Back Pain (NSCLBP) and Healthy Controls
R Hemming, L Sheeran, R van Deursen, V Sparkes
Physiotherapy Research Society, Loughborough, April 2015 (Platform presentation)

Regional spinal kinematics during static postures: discrimination between sub-classified people with non-specific chronic low back pain (NSCLBP) and healthy controls
R Hemming, L Sheeran, R van Deursen, V Sparkes
Society of Back Pain Research, Dublin, November 2014 (Platform presentation)

Sub-classification of non-specific chronic low back pain: evaluation of spinal movement patterns
R Hemming, L Sheeran, R van Deursen, V Sparkes
Oliver Bird Rheumatism Conference, London, September 2014 (Platform presentation)

Regional Spinal Kinematics during Static Postures: Discrimination between Sub-classified Non-specific Chronic Low Back Pain Patients and Healthy Controls
R Hemming, L Sheeran, R van Deursen, V Sparkes
2nd South West Regional Regenerative Medicine Meeting, Llanelli, September 2014 (Platform presentation)

Within- and Between-Day Reliability of Functional Movements in Healthy Subjects Using 3D Motion Analysis: A Preliminary Study
Hemming R, Sheeran L, Roos P, van Deursen R, Sparkes V
8th Interdisciplinary World Congress on Low Back & Pelvic Pain, Dubai, October 2013 (e-poster presentation)

Classification-based cognitive functional group intervention in sub-groups of non-specific chronic low back pain: Preliminary Results
Sheeran L, Hemming R, van Deursen R, Sparkes V
8th Interdisciplinary World Congress on Low Back & Pelvic Pain, Dubai, October 2013 (e-poster presentation)

Cognitive Functional Feedback Intervention in Subgroups of Non-Specific Chronic Low Back Pain: A Feasibility Study
Sheeran L, Hemming R, van Deursen R, Sparkes V
Physiotherapy Research Society 32nd Scientific Meeting, Cardiff, April 2013 (Platform presentation)

Within- and Between-Day Reliability of Functional Movements in Healthy Subjects Using 3D Motion Analysis: A Preliminary Study
Physiotherapy Research Society 32nd Scientific Meeting, Cardiff, April 2013 (poster presentation)
Award: Best academic poster-1st prize

Differences in Trunk Muscle Activity and Posture During Reaching Tasks Between Subjects with a History of Back Pain and Those Without
Sparkes V, Cross B, Pask H, Wing R, Hemming R, Meana-Esteban A, Sheeran L
Society of Back Pain Research, Isle of Man, November 2012, UK (Platform presentation)

Sub-classification of Patients with Non-Specific Chronic Low Back Pain: Evaluation of the Spine during Functional Tasks
Arthritis Research UK Conference, Loughborough, October 2012 (poster presentation)

A Systematic Review of Marker sets for the Evaluation of Spinal movement using Opto-electronic Devices
2nd South West Regional Regenerative Medicine Conference, Bristol, September 2012 (poster presentation)

A Comparison of Marker sets for the Evaluation of Spinal movement using Opto-electronic Devices
SysNet Inaugral Conference, Cardiff, April 2012 (poster presentation)
Award: Best academic poster-2nd prize

Sub-classification of Patients with Non-Specific Chronic Low Back Pain: Evaluation of the Spine during Functional Tasks
Inaugural South West Regional Regenerative Medicine Meeting, Bristol, September 2011 (poster presentation)

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List of Abbreviations

AEP	Active Extension Pattern
ANOVA	Analysis of Variance
BMI	Body Mass Index
CAT	Critical Appraisal Tool
CB-CFT	Classification Based Cognitive Functional Therapy
CLBP	Chronic Low Back Pain
CS	Classification System
DRAM	Distress and Risk Assessment Method
EMG	Electromyography
EO	External Oblique
FLSP	Flexion Lateral Shift Pattern
FP	Flexion Pattern
FRP	Flexion Relaxation Phenomenon
ICC	Intraclass Correlation Coefficient
IPAQ	International Physical Activity Questionnaire
IPAQ-SF	International Physical Activity Questionnaire (Short Form)
LBP	Low Back Pain
LBD	Low Back Discomfort
LM	Lumbar Multifidus
LT	Longissimus Thoracis (Erector Spinae)
MCI	Motor Control Impairment
MDCS	Multi-directional Classification System
MDP	Multidirectional Pattern
MSPQ	Modified Somatic Perceptions Questionnaire
MVC	Maximal Voluntary Contraction
MZDI	Modified Zung Depression Index
NISCHR	National Institute for Social Care and Health Research
NRS	Numerical Rating Scale
NSCLBP	Non-Specific Chronic Low Back Pain
ODQ	Oswestry Disability Questionnaire
OBD	Overall Body Discomfort

PEP	Passive Extension Pattern
PROM	Patient Reported Outcome Measure
RCT	Randomised Controlled Trial
TrA/IO	Transversus Abdominis / Internal Oblique
SD	Standard Deviation
SEM	Standard Error of Measurement
sEMG	Surface Electromyography
sLM	Superficial Lumbar Multifidus
SMVC	Sub-Maximal Voluntary Contraction
SPS	Spinal Position Sense
S-W	Shapiro-Wilk
TSK	Tampa Scale of Kinesiophobia
VAS	Visual Analogue Scale

1 INTRODUCTION

Low back pain (LBP) contributes the greatest proportion of worldwide disability (Hoy et al. 2014), with an anticipated lifetime prevalence of up to 84%, approximately 23% of whom will go on to develop chronicity (symptoms persisting beyond 12 weeks) (Airaksinen et al. 2006). Current UK figures suggest the general population prevalence of chronic low back pain (CLBP) to be as high as 11.1% (Juniper et al. 2009; Waxman et al. 2000). Annual direct healthcare costs in the UK were reportedly approximately £1632 million (£10668 million overall cost to the economy) in 1998 (Maniadakis and Gray 2000), with more recent estimations believing this cost to have subsequently increased by 28.8% (National Institute for Health and Clinical Excellence. 2009). Thus CLBP remains one the highest healthcare priorities for modern society.

Acute LBP symptoms resolve in the majority of cases, however a significant proportion of individuals (10-59%) report symptoms lasting more than 12 weeks (Henschke et al. 2008; Schiøttz-Christensen et al. 1999; van Tulder et al. 2006). Often LBP cannot be attributed to a specific pathological or structural cause with no definitive diagnosis confirmed through radiological investigation. For these individuals pain is termed 'non-specific' (Balagué et al. 2012). Non-specific chronic low back pain (NSCLBP) is a complex heterogeneous biopsychosocial disorder with multiple manifestations (Airaksinen et al. 2006) and despite considerable research into the disorder there is little reported change in long-term prognosis (Foster et al. 2013). Intervention outcomes in these populations are usually only short-term with mean beneficial effects shown to be moderate at best (Balagué and Dudler 2011; Patel et al. 2013). No specific interventions have been identified which is likely to be due to an inability to define clear homogeneous NSCLBP sub-groups (Foster et al. 2011). Current NSCLBP research approaches generally consider NSCLBP as a single homogeneous group potentially concealing distinct subgroups. Thus a 'wash-out' effect may be observed whereby interventions effective for some subgroups may not be effective for others (Rose 1989). For several years now the ability to identify specific NSCLBP sub-groups using validated subclassification approaches has been highlighted as a key research priority (Foster et al. 2011; Ping et al. 2005).

Multiple classification systems have been proposed, however a biopsychosocial classification system with emerging validity to subgroup NSCLBP into individuals with maladaptive motor control impairments (MCI) has been proposed (O'Sullivan 2005). This Multi-Dimensional Classification System (MDCS) has established that distinct physical characteristics between two of the proposed MCI subgroups (Active Extension Pattern and Flexion Pattern) and healthy subjects in adolescent and adult populations are evident. This has been established with regard to alterations in spinal position

sense (SPS), spinal kinematics and trunk muscle activity during static postures (Astfalck et al. 2010b; Dankaerts et al. 2006a, c; Sheeran et al. 2012). These MCI subgroups have also been shown to respond positively to targeted subgroup intervention when compared with usual care (Fersum et al. 2013; Sheeran et al. 2013).

Clinically, functional activities (e.g. sitting to standing, bending), alongside static postures, are often reported as pain provoking. Although it has been established that specific postural differences exist with regard to static postures in the AEP and FP groups, no published work to date has evaluated how NSCLBP MCI subgroups operate during dynamic functional activities. It may be that pain provocative maladaptive postures observed statically are present throughout all functional tasks and thus postural re-education strategies alone may be insufficient to address maladaptive functional movement behaviours. Classification-based cognitive functional therapy (CB-CFT) approaches have also been proposed to be effective for these subgroups (Fersum et al. 2013) despite no literature specifically exploring functional movement strategies in these patient subgroups. Establishing potential differences in spinal movement patterns and muscle activation patterns in these subgroups compared to healthy subjects would therefore aid in better informing targeted subgroup functional interventions (such as CB-CFT) to improve long-term prognosis in NSCLBP.

This thesis aims to explore this gap in the current literature, whilst acknowledging and addressing some of the current methodological challenges of reliably and validly measuring dynamic trunk movement (spinal kinematics and trunk muscle activity) to establish if subgroup differences are observed between subgroups of NSCLBP patients and healthy individuals during functional tasks.

2 LITERATURE REVIEW

2.1 Literature Search Strategy

The primary aim of this literature review was to identify relevant literature concerning subclassification strategies for NSCLBP and MCI, spinal kinematics and muscle activity during static, range of movement (ROM) and functional activities in healthy and NSCLBP cohorts and methodological approaches to evaluation of spinal biomechanics.

In order to effectively evaluate these aspects the literature review was conducted in four key areas:

- Epidemiology and classification of NSCLBP
- Motor control impairment of the spine
- Spinal kinematics and trunk muscle activity in NSCLBP and healthy subjects
- Biomechanical methods for evaluation of the spinal kinematics and muscle activity

The search was conducted using the following relevant, medically based, databases: AMED, Cinahl, PEDro, Scopus, PubMed, Medline via Ovid and the Cochrane library. Details of the search strategy and keyword search terms can be found in Appendix I. There are large volumes of literature investigating the broad and complex area of NSCLBP therefore articles were limited to the English language only. Articles were only included from the previous 20 years, unless cross-referenced or cited in articles of interest. With regard to the systematic review, all articles previously published were included in the review to ensure that all possible references were covered.

2.2 Low Back Pain: An Overview

2.2.1 The Problem of Low Back Pain

Low back pain (LBP) is a costly and complex global phenomenon reportedly causing more disability worldwide than any other condition (Hoy et al. 2014). Up to 11.1% of the UK general population are believed to suffer from CLBP at any one time (Juniper et al. 2009; Waxman et al. 2000) with lifetime prevalence of LBP reportedly as high as 84%, with approximately 23% of individuals developing chronic pain persisting beyond 12 weeks (Airaksinen et al. 2006). Although clinical 'evidence-based' guidelines for guiding chronic low back pain management have been implemented by healthcare professionals (Airaksinen et al. 2006; National Institute for Health and Clinical Excellence. 2009) the incidence of LBP is widely reported to be in status quo among the general population (Deyo et al. 2006; Huppe et al. 2007) with some studies even identifying increasing trends (Freburger et al. 2009; Harkness et al. 2005). The problem of LBP impacts not only upon the individual's quality of life, but also on the wider economic picture and is thus a key area for identifying effective, targeted interventions.

Broadly speaking, LBP can be considered to be either pain attributed to a serious or specific underlying pathology or a 'non-specific' cause. Serious underlying pathology, often referred to as 'red flags', includes spinal malignancy, inflammatory disorders (such as rheumatoid arthritis), infections, spinal fracture and cauda equina syndrome and require immediate medical assessment (Koes et al. 2010; van Tulder et al. 2006; Waddell 2004). Specific underlying pathological changes are any structural changes which can be directly attributable to the patient's symptoms, for example disc prolapse, stenosis, and spondylolisthesis (Koes et al. 2006).

Chronic low back pain (CLBP), pain which persists for more than 12 weeks, beyond usual expected tissue healing times, may not always exhibit a clear underlying patho-anatomical, or even pathological, cause (Andersson 1999; O'Sullivan 2005). For the vast majority (85%) of CLBP sufferers no definitive diagnosis can be attained (Waddell 2004).

2.2.2 Non-Specific Chronic Low Back Pain

Airaksinen et al. (2006) reports CLBP to be a multi-factorial problem, rather than a diagnosis or 'clinical entity', which incorporates patient presentations with differing levels of impairments, disability and chronicity. These symptoms are termed 'non-specific' when the pain experienced by an individual cannot be attributed to a specific pathological cause, for example inflammation,

osteoporosis, fracture, malignancy, disc pathology, radicular symptoms, cauda equina or any structural deformity (Balagué et al. 2012) and a definitive diagnosis cannot be attained through radiological investigation. Even when a specific diagnosis or structural anomaly is identified radiologically using plain radiographs or more advanced imaging techniques, radiologically identified structural findings have been shown to correlate poorly with low back pain symptoms (Boden et al. 1990; Jensen et al. 1994; Powell et al. 1986; van Tulder et al. 1997). Current guidelines recommend the omission of radiology as a diagnostic tool for CLBP due to the high level of incidental findings, unless a specific structural cause is suspected (Airaksinen et al. 2006; National Institute for Health and Clinical Excellence. 2009).

There has been little change to long-term prognosis of NSCLBP, despite a steady increase in research in this area (Foster et al. 2013). A systematic review of randomised controlled trials (RCTs) reported that current intervention approaches produce short-term, small-to-moderate mean beneficial effects in NSCLBP (Patel et al. 2013), with no single, clear, beneficial treatment strategy identified. It has been advocated that this is due to the heterogeneity of NSCLBP where a 'one size fits all' principle is unlikely to apply. Significant improvements seen in a proportion of a subject cohort may be cancelled out by a minimal effect in another subject group, leading to a 'wash-out' effect as described by Rose et al (1989). Another hypothesis is that traditionally treatment for this heterogeneous NSCLBP group has been targeted at addressing presenting signs and symptoms rather than potential underlying pain mechanisms (Dankaerts and O'Sullivan 2011). When specific mechanisms underlying LBP are known, treatments specifically targeting the cause rather than purely the signs and symptoms may be much more clinically effective (Zimny 2004). Thus an ability to accurately identify specific NSCLBP sub-groups has been highlighted as a key research priority to establish sub-groups of patients for which underlying mechanisms for pain and disability can be identified (Foster et al. 2011; Ping et al. 2005). If this can be achieved, and subsequently validated both clinically and experimentally, specific interventions can be developed to stratify care by identifying which patient sub-groups best respond to specific intervention (Airaksinen et al. 2006; Foster et al. 2013).

2.2.3 The Biopsychosocial Model of Low Back Pain

The biopsychosocial model of low back pain as a conceptual model of LBP was first proposed by Waddell (1987) and there is widespread consensus that a 'biopsychosocial' approach to back pain management is fundamental to understanding and addressing the challenge of NSCLBP. The European Guidelines on the management of NSCLBP recommend yellow flags (psychosocial factors which may be contributory factors to pain perception) to be included as an integral aspect of clinical assessment (Airaksinen et al. 2006). Psychosocial factors are considered to be psychological and social influences which can contribute to pathophysiological changes in CLBP, for example increases

in muscle activity and tension which may alter spinal loading and subsequent physiological changes to other spinal structures such as the intervertebral discs and nerve root (Bergenudd and Johnell 1991; Bongers et al. 1993). Psychosocial factors include fear avoidance (Boersma and Linton 2006; Leeuw et al. 2007), catastrophising (Smeets et al. 2006; Turner et al. 2000), depression (Grotle et al. 2005; Henschke et al. 2008), self-efficacy (Hilfiker et al. 2007), patient expectations and beliefs about their condition (Hilfiker et al. 2007; Symonds et al. 1996) and perception of illness (Foster et al. 2008).

Fear of movement and subsequent avoidance strategies are also believed to be a key contributory factor to chronic pain development and motor control dysfunction (as discussed in section 2.4). It is hypothesised that some LBP individuals may avoid activities as a spontaneous reaction to acute pain (Wall 1979). A proposed model for the role of fear avoidance as a mediator in pain chronicity is illustrated in Figure 1. Behavioural performance in relation to fear of movement in CLBP has been previously evaluated during lifting tasks (Vlaeyen et al. 1995) where CLBP patients with high Tampa Scale of Kinesiophobia (TSK) scores (>37) were identified to be more likely to avoid motor activities (i.e. replace the weight earlier) compared to subjects with low TSK scores. Although, moderate correlation between TSK scores and visual analogue scale (VAS) scores were identified, Vlaeyen et al. (1995) argues that pain intensity is not a strong predictor of fear of movement with fear avoidant behaviours appearing to occur independently of pain intensity.

(Vlaeyen et al, 1995)

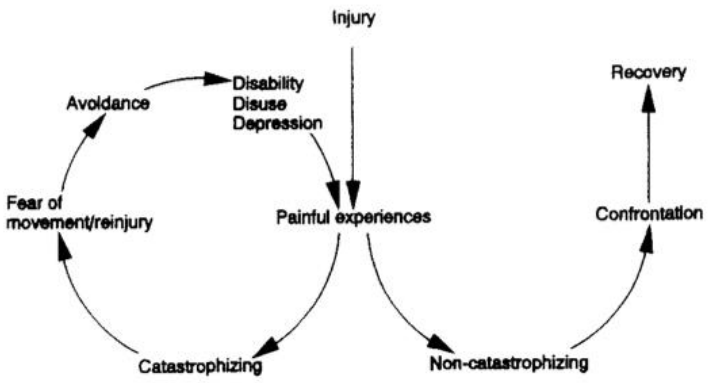


Figure 1: Cognitive-behavioural model of fear of movement / (re)injury

Thus the integral nature of psychosocial factors on back pain experience cannot be ignored. It is essential that future CLBP studies screen patients to determine the magnitude of psychosocial factor influence on clinical presentation. Clinically, psychosocial factors should be comprehensively assessed for each individual to inform tailored treatment approaches for specific patient groups and improve clinical outcomes. The biopsychosocial framework is therefore fundamental to better understanding the complexity of NSCLBP. Thus identifying subclassification approaches that are founded on a biopsychosocial framework is important for implementing targeted care.

2.3 Subclassification of Non-Specific Chronic Low Back Pain

2.3.1 Overview of Classification Systems

Assumed sample homogeneity has been proposed to be a key factor in the moderate treatment outcomes observed in CLBP (Balagué and Dudler 2011; Hush and Marcuzzi 2012), thus the ability to accurately identify heterogeneous sub-groups within the NSCLBP population has been the source of great attention in recent years. However, the ability to validate subclassification approaches remains a challenge due to the complexity of the disorder and unique pain experience for each individual.

With the increasing prioritisation of NSCLBP subclassification in research and clinical practice, many classification systems (CS) have been proposed. Effective CS aim to identify homogenous sub-groups demonstrating maximum between group heterogeneity. A distinct disadvantage of many CS however is a uni-dimensional focus whereby only a single contributory factor to the disorder is considered. Examples of such uni-dimensional CS include those based upon: Patho-anatomical features (Nachemson 1999; Petersen et al. 2003); clinical features (Delitto et al. 1995; McKenzie 1981; McKenzie and May 2003; Van Dillen et al. 1998; Van Dillen et al. 2003); psychological features (Bergström et al. 2001; Coste et al. 1992; Keefe et al. 1990; Klapow et al. 1993; Main et al. 1992; Ozguler et al. 2002) and work status (Halpern 2001; Krause and Ragland 1994). When considered in combination these models can provide a more comprehensive biopsychosocial approach to subclassification, however alone, these approaches fail to account for the complex nature of NSCLBP with no single uni-dimensional approach shown to demonstrate sufficient evidence for research or clinical utility (Ford et al. 2007; McCarthy et al. 2004; Petersen 1999; Riddle 1998). A lack of consideration of the complex biopsychosocial nature of CLBP within these CS could be hypothesized to be a contributory factor to the lack of treatment specificity in this patient population (Rabey et al. 2015). Biopsychosocial CS which consider all contributory factors are widely considered to be the most appropriate approaches to back pain subclassification (Borkan et al. 2002; O'Sullivan 2005), however only approximately 10% of current CS are based on a biopsychosocial approach (Billis et al. 2007).

Additionally, despite the plethora of classification approaches relatively few NSCLBP CS outline specific intervention approaches for subgroups or utilise subclassification approaches to evaluate clinical outcomes following targeted intervention. Fersum et al (2010) identified only 5 articles (between 1998 to 2008) incorporating NSCLBP subclassification in evaluation of the effectiveness of manual and exercise therapy (Gudavalli et al. 2006; Petersen et al. 2002; Riipinen et al. 2005; Snook et al. 1998; Vollenbroek-Hutten et al. 2004). Classification-driven interventions were identified to

produce statistically significant improvements for pain scores (p=0.004) and disability (p=0.0005) compared to studies omitting a subclassification strategy. Therefore classification systems based on a clear biopsychosocial framework with proposed management strategies are clearly advantageous.

2.3.2 Biopsychosocial Classification Systems

Examples of CS' developed around a biopsychosocial framework include: The STarT Back Tool (Hill et al. 2008; Hill et al. 2010; Hill et al. 2011); the Quebec Task Force Classification (QTFC) (Spitzer et al. 1987); and the Multidimensional Classification System (MDCS) (O'Sullivan 2005).
Hill et al. (2008) developed a biopsychosocial subclassification tool (STarT Back) to identify physiotherapeutic management routes for LBP individuals based on prognostic factors. The patient-completed questionnaire subgrouped LBP patients based on potentially modifiable prognostic indicators from which patients are stratified into specific care pathways based on low, medium or high risk of poor prognosis (chronicity). However STarT Back does not consider biomechanical or physical patient presentation (other than radiculopathy), thus it is not fully understood whether differences in clinical presentation may be contributory factors to poor prognosis. Additionally, although STarT Back appears useful in differentiating between low and high risk groups, the medium risk group receive standard physiotherapeutic intervention with specificity of treatment for each group not detailed. In an RCT sub-groups of NSCLBP (n=922) identified using the STarT Back tool were compared with "best current care" (Hill et al. 2011). Low risk candidates were provided with physiotherapy advice, reassurance and education; medium risk individuals received standard physiotherapy care delivered over six 30 minute sessions; and high risk groups received this same physiotherapy care with additional cognitive-behavioural input. At the 6-month follow-up, a small, significant improvement in disability scores (Roland Morris Disability Questionnaire (RMDQ)) score (0.7 (95% CI, 0.1–1.4)) was observed in the stratified care group, compared to usual care. Interestingly, a larger difference in RMDQ score was observed in the high-risk group (2.3 (95% CI, 0.8–3.9)), which may indicate that the tool is important for detecting patients at risk of psychological distress who may gain additional benefit from cognitive interventions. This observation may also be reflected in the reported reduction in mean time of absenteeism from work (50% reduction: 4 vs. 8 days, p=0.03) and proportion of patients provided with sickness certifications (30% reduction: 9% vs. 15%, p=0.03) in the stratified care group. This demonstrates the STarT Back to be a clearly beneficial tool for practitioners, especially in determining the lowest and highest risk NSCLBP patients. However it could be argued that little is currently understood about the 'medium risk' patient group who receive seemingly routine physiotherapeutic intervention and thus for whom further subgrouping approaches need to be explored. This medium risk group is likely to be the group presenting with 'dysfunction', as opposed to the 'active copers' (low risk) or the distressed patients (high risk). Thus

determining which patients within this ‘medium risk group’ respond best to which interventions remains to be established. Further CS are therefore required to better understand potential management strategies for these individuals.

Clinical assessment performed by a healthcare practitioner therefore also needs to be considered, alongside self-reported questionnaires, as an important aspect of the NSCLBP management puzzle. One such example of this is the QTFC (Spitzer et al. 1987) which is commonly implemented clinically (Werneke and Hart 2004). The QTFC considers the chronicity of the disorder (acute, sub-acute or chronic) and the underlying mechanism for LBP either as ‘specific’ (i.e. nerve root pain) or ‘non-specific’. Importantly the framework also considers: red flags; patho-anatomical diagnoses; clinically evaluated and patient reported signs and symptoms; and psychosocial factors (including yellow flags and work status) (Spitzer et al. 1987). The QTFC also, importantly, outlines a potential, albeit generic, management plan for the NSCLBP group. Although the QTFC has been demonstrated to discriminate between baseline pain intensity and disability in an acute LBP cohort (n=171) when classified by physiotherapists, it may be unable to predict pain intensity on discharge or work status at 1 year (Werneke and Hart 2004). Subgrouping LBP patients using the QTFC by location of pain and neurological signs in the lower limb has been shown to be associated with activity limitation and sickness absence, however no clear associations in these variables were identified in patients without neurological signs (Kongsted et al. 2013). Thus it may be argued that for clinicians the QTFC may be of greater value in differentiating between somatic and radicular pain. As the QTFC does not consider NSCLBP subgroups, the potential underlying mechanisms for the pain disorder are not defined limiting its application for stratifying patients towards suitable treatment approaches (Dankaerts et al. 2006d).

It is acknowledged that generally LBP patients do not easily fall into a single classification system, thus understanding the multiple dimensions of LBP and how these dimensions interact may be more helpful for clinical application (Rabey et al. 2015). CLBP CS’ need to be flexible, clinically useful and show consideration of all potential LBP dimensions (Rabey et al. 2015). A multidimensional classification system (MDCS) (O'Sullivan 2005) was developed based on the QTFC to concurrently consider patho-anatomical diagnoses, patient signs and symptoms and psychosocial factors within a biopsychosocial context. Importantly the MDCS outlines a proposed treatment approach, integrating subgroup specific cognitive and functional therapeutic approaches. Inter-examiner reliability for the CS between expert and novice clinicians has been established cross-culturally (Dankaerts et al. 2006d; Fersum et al. 2009) and a robust evidence base is emerging with regard to muscle activity and spinal kinematics in both adult (Dankaerts et al. 2006a, c; Dankaerts et al. 2009; Dankaerts et al. 2007; Fersum et al. 2013) and adolescent populations (Astfalck et al. 2013; Astfalck et al. 2010a; Astfalck et

al. 2010b) during static postures. Thus the MDCS has been selected as the CS to be evaluated as part of this thesis. The rationale and evidence base for this approach is outlined in section 2.3.3.

2.3.3 The Multidimensional Classification System for NSCLBP

2.3.3.1 Overview

O'Sullivan (2005) suggests that locally reported pain which can be consistently replicated through specific mechanically-driven aggravating and easing factors may be suggestive of pain attributable to a mechanical cause (i.e. pain moderated by peripheral nociceptive pathways). Conversely, it is the clinical opinion of O'Sullivan (2005) that diffuse, constant pain with a less specific relationship to mechanical factors may be more likely to be attributable to a centrally mediated pain disorder (neurophysiological pain response). It is proposed that in some cases psychosocial factors (e.g. hyper-vigilance, fear, anxiety, guarding responses) primarily drive the pain response, through resultant dominant forebrain excitability (Linton 2000). It is recognised that most LBP patients may present with a combination of factors to a greater or lesser extent, where clinical judgement is required to determine the dominance of such factors (O'Sullivan 2005).

Based on these initial observations by O'Sullivan (2005) the MDCS proposed 3 broad sub-groups for CLBP based upon the proposed primary mechanisms for the pain which are outlined below. A full detailed outline of the MDCS is presented in Appendix II.

The first group identifies patients for whom the significant presence of psycho-social factors are the primary driver for the pain disorder resulting in activation of forebrain activity to induce a centrally mediated pain response (Linton 2000). The second group considers patients who have specific patho-anatomical structural changes, or serious pathology (red flags), which may lead to secondary adaptive motor (movement and / or control) impairments. For these individuals the primary mechanism driving the pain may be structural not adaptive, which may require alternative interventions to address the underlying structural cause (e.g. surgical, pharmaceutical) (O'Sullivan 2005). The third group encompasses the majority of CLBP patients. O'Sullivan (2005) proposes that these individuals present with maladaptive responses to pain resulting in either impairment of movement or motor control influencing changes in tissue loading over time. These pain mechanisms appear to be primarily mechanically driven, where secondary cognitive adaptations and altered psychosocial behaviours may continue to drive patients into a pattern of on-going pain, disability and in some instances, distress (Frymoyer et al. 1985; Hodges and Moseley 2003). Treatment approaches for both the movement and

motor control groups involves resolution of symptoms by 'normalising' maladaptive behaviours through integrated therapy targeting both physical and cognitive impairments.

Table 1 details the clinical presentation of both movement and motor control impairments as described by O'Sullivan (2005).

Table 1: Outline of the clinical presentation of (A) Movement Impairment Classification and (B) Control Impairment Classification

Movement Impairment Classification	Control Impairment Classification
Nature and mechanism of pain: Localised pain +/- referral Severe pain of rapid onset Movement impairment in direction of pain Hyper-awareness of pain Exaggerated reflex withdrawal motor response Muscle guarding and abnormal tissue loading (increased spinal stability) Avoidance of movement into painful range	Nature and mechanism of pain: Localised pain +/- referral Gradual onset of pain from repeated or sustained strain No impaired movement in direction of pain Lack of awareness of pain triggers Poor lumbo-pelvic position sense Absence of reflex withdrawal motor response Ongoing tissue strain (increased or decreased spinal stability) Provocation into painful range Avoidance of painful activity
Disability Directional (flexion, extension, rotation, lateral shift, loading) Multi-directional	Disability Directional (flexion, extension, rotation, lateral shift, loading) Multi-directional
<u>Result:</u> Peripheral pain sensitisation	<u>Result:</u> Peripheral pain sensitisation
Anxiety related to movement pain Fear avoidance when moving in direction of pain (pathological) Hyper-vigilance Belief that pain is damaging (pathological)	Anxiety related to chronic disabling pain Fear of activity (non-pathological) Lack of control and awareness of disorder Belief that activity is damaging (non-pathological)
<u>Result:</u> Central pain sensitisation	<u>Result:</u> Central pain sensitisation
Normalisation of movement impairment leads to resolution / control of disorder	Normalisation of control impairment leads to resolution / control of disorder

(Adapted from O'Sullivan (2005))

2.3.3.2 Motor Control Impairment

Earlier research by O'Sullivan et al (1997) evaluating motor control of the lumbar spine in patients with radiological evidence of spondylolysis or spondylolisthesis found that most participants presented with full spinal ROM with pain reported through range or in neutral (midrange) sustained postures, rather than at end range, highlighting that MCI may a primary driver for pain rather than pain derived from aggravation of passive structures at end ROM (O'Sullivan 2005).

MCI are proposed to be the most common clinical presentations of CLBP, where the patient is clinically considered to display an impairment of control of the symptomatic spinal segment in the direction of the primary source of pain (O'Sullivan 2005). In contrast to the movement impairment group this patient group display full ROM in the direction of pain provocation and are clinically observed to habitually adopt end range postures that could be hypothesised to chronically stress pain sensitive spinal tissues. Similarly to the movement impairment patients, MCI patients have been shown to display high levels of fear avoidance to adopt postures and movement strategies that promote increased pain (Dankaerts et al. 2006a, c). Interestingly, these patients have been shown to demonstrate a lack of awareness of adopting end range, pain provocative postures (Burnett et al. 2004; Dankaerts et al. 2006c; O'Sullivan 2004). These maladaptive postural strategies may develop as a result of proprioceptive deficits and an absence of the withdrawal reflex motor response being initiated in the presence of chronic, insidious pain (Burnett et al. 2004; O'Sullivan et al. 2003) however, to date, this hypothesis has not been substantiated. Normalisation of the impairment for MCI patients is proposed to involve patient education to reduce fear and promote postures and spinal control through functional activity which does not cause end range repetitive strain and reduce spinal loading which in turn should to reduce peripheral nociceptor sensitivity (O'Sullivan 2005).

O'Sullivan (2005) observed that for most patients MCI are directional with 5 classification MCI subgroups proposed: flexion pattern (FP), active extension pattern (AEP), passive extension pattern (PEP), flexion lateral shift pattern (FLSP) and multi-directional pattern (MDP) MCI (combination of two or more directional impairments). A full description of each MCI pattern is given in detail in Appendix II. Clinically, AEP and FP MCI are most commonly observed. O'Sullivan (2005) proposes that FP MCI is ordinarily associated with poor activity and control of the spinal stabilising musculature, whereas it is proposed that the AEP patients may present with increased spinal muscle activity and subsequent increases in spinal loading. A table detailing the clinical characteristics for these two MCI groups is depicted in Table 2. The characteristics of these MCI patterns were proposed and developed through clinical observation, thus the robustness of the CS remains a consideration.

Table 2: Key clinical features of flexion and active extension pattern

Flexion Pattern (FP)	Active Extension Pattern (AEP)
Aggravation of symptoms with movements and postures involving flexion of the lower lumbar spine	Aggravation of symptoms with movements and postures involving extension of the lower lumbar spine (commonly reported as a provocative activity is forward bending and sitting, with the key feature here being the tendency to hold the lumbar spine into segmental hyper-extension)
Loss of segmental lordosis at symptomatic level, difficulty assuming and/or maintaining neutral lordotic postures with a tendency to drop into flexion	Excess of segmental lordosis at symptomatic level with posture and movements
Pain relief with spinal extension	Difficulty assuming and/or maintaining neutral lordotic postures with a tendency to position themselves into hyper-extension
	Pain relief with spinal flexion

(adapted from Dankaerts and O'Sullivan, 2011)

2.3.3.3 Reliability of the Classification System

A key aspect of any classification system designed for clinical implementation is the reliability of consensus between clinicians. Inter-tester reliability of subclassifying NSCLBP using the MDCS between expert clinicians and less experienced clinicians who have been trained in the approach has been established (Dankaerts et al. 2006d). Excellent agreement between expert clinicians was observed (kappa-coefficient 0.96, % agreement 97%) in the subclassification of 35 NSCLBP patients (into all 5 proposed MCI subgroups). This consensus is perhaps unsurprising when considering the level of exposure to the CS the clinicians previously had: the classification system developer (O'Sullivan), and a clinician with 12 years experience who had received extensive training in the use of the classification system (Dankaerts). It is also a consideration that only two 'expert' clinicians were examined thus limiting the extent to which the results are clinically generalisable, however the findings demonstrate a clear consensus on the existence of these subgroups and provide a baseline comparison to evaluate agreement between novice users of the MDCS. In the 2nd phase of the study, videotapes of the subjects evaluated by the expert clinicians, together with the subjective information, were sent to 13 clinicians (physiotherapists and general practitioners) in Western Australia and Norway for subclassification. Substantial reliability between clinicians was observed (mean kappa-coefficient 0.61, mean %-of-agreement 70%). Both mean kappa-coefficient and agreement were reduced when only subjective information was considered (0.32, 48% respectively) highlighting the

importance of the objective examination. Clinician familiarity with the MDCS was also evaluated ('moderately familiar' n=8; or 'very familiar' n=5). Less familiarisation with the MDCS demonstrated reduced levels of agreement (78% compared to 65%) with the AEP least correctly identified (62%) and FLSP the best identified (82%). Variability in the identification of MCI sub-groups may lead one to hypothesise whether there are aspects of the MDCS subgroup presentations that have been overlooked, or whether for example the AEP-MCI group may conceal further subgroups. Further research evaluating specific movement pattern during functional movements within these MCI sub-groups may improve understanding of the biomechanical presentation of these subgroups to ascertain whether certain MCI impairments (e.g. AEP) accurately reflect clinical patient presentations, or whether certain further consideration of the subgroups within the MDCS framework are needed. For clinicians with high levels of familiarisation and training with the MDCS Dankaerts et al's (2006d) observations support the use of the MDCS as a reliable classification tool. Evaluation of novice clinicians was conducted in a small sample of clinicians (n=13, across 2 countries), limiting the generalisability of the findings. The training delivered to these clinicians appears was predominantly delivered by the system developer, which may introduce an element of bias, as well as limiting the clinical applicability and feasibility of this approach. Additionally the method of delivery of training (i.e. face-to-face, video conference etc.) is not specified and the length of time required to conduct the patient assessment, which is an important consideration for clinical practice in order for a CS to be feasible is not reported.

Inter-examiner reliability of the MDCS has also been established between 4 experienced clinicians in a small NSCLBP sample (n=26) (Fersum et al. 2009). MCI classification in relation to directional pain provocation demonstrated a Kappa agreement of 0.82 (range 0.66-0.90), and mean percentage agreement of 86% (range 73-92%) demonstrating moderate to good inter-tester reliability in support of Dankaerts et al's (2006d) observations. In accordance with Dankaerts et al. (2006d), AEP was the most variable MCI to classify, with only 50% correctly identified further highlighting the potential concealment of additional subgroups within this MCI pattern. All other MCI groups demonstrated a minimum of 75% mean percentage agreement between clinicians (FP 79.1%, MDP 75%, FLSP 75%, PEP 100%), however a substantial percentage of MCI patterns were incorrectly identified indicating MCI patterns to be potentially variable in clinical presentation. Dankaerts et al's (2006d) and Fersum et al's (2009) studies are limited in application by defining the use of 'expert' clinicians (including the principle MDCS developers) as the 'gold standard', leading to potential bias. Additionally the clinicians evaluated in Fersum et al's (2009) study received training delivered by the MDCS developer (O'Sullivan), limiting comparisons with routine clinical practice.

The absence of a true 'gold standard' for diagnosing MCI impairment is acknowledged by both Dankaerts et al. (2006d) and Fersum et al. (2009) however it could be conversely argued that the use

of expert clinicians may be a model most relevant and transferable to a clinical environment (Dankaerts and O'Sullivan 2011; Gracovetsky et al. 1995).

Overall, these studies demonstrate good agreement between clinicians (with differing levels of familiarisation with the MDCS) to support the clinical viability of such an approach. The findings also support the face validity of the MDCS, with clinicians with limited experience of the MDCS able to consistently define patient subgroups. To the best of the authors knowledge, no studies have yet evaluated spinal kinematic and muscle activity in MDP, FLSP and PEP MCI, although Fersum et al. (2009) suggests that these patterns are real phenomena and can be consistently identified by clinicians, albeit in small numbers. Further research is required to evaluate these MCI patterns using kinematics and surface electromyography (sEMG) to validate their existence.

2.3.3.4 Evaluation of Spinal Kinematics in MCI Subgroups

For widespread clinical implementation of the MDCS, comprehensive understanding of differences in physical (or biomechanical) characteristics of the MCI patterns needs to be clearly understood. FP and AEP patients are purported to demonstrate difficulty adopting neutral postures with a natural lordosis of the spine, however the FP patients are proposed to habitually assume a more flexed spinal profile whilst the AEP patients are proposed to adopt significantly more hyper-extended posture profiles (O'Sullivan 2004). These MCI subgroup postural differences have been explored previously in static postures.

Differences in lumbo-pelvic angles between a homogenous pooled-NSCLBP group compared to reportedly heterogeneous subgroups of NSCLBP (AEP and FP) has been established in sitting (Dankaerts et al. 2006b). Sacral tilt, lower lumbar (L3 to S2), and upper lumbar (T12 to L3) angles were evaluated in 33 NSCLBP patients (20 FP and 13 AEP) and healthy subjects (n=34) in usual and slumped sitting. No significant differences were identified between the healthy controls and pooled NSCLBP subjects in usual sitting postures although the pooled NSCLBP group expressed a reduced ability to alter their neutral posture when changing between usual sitting and slumped sitting postures, suggesting reduced spinal awareness, or avoidant movement strategies in response to pain (O'Sullivan 2005). The heterogeneous nature of the 'pooled' group may have produced a 'wash-out' effect (Rose 1989) where postural extremes of range were counteracted by the inclusion of individuals displaying opposing characteristics. Interestingly, following classification using the MDCS significant between group differences were observed. In usual sitting significant differences were observed in the upper lumbar region between the AEP group and both the FP and healthy groups ($p<0.001$), between all 3 groups (AEP, FP, healthy) in the lower lumbar region ($p<0.001$) and between the FP group and both

the AEP and healthy group with regards to sacral tilt ($p<0.001$). In all instances the AEP group adopted more extended lumbar-pelvic postures; FP more flexed lumbar-pelvic posture; with the healthy group consistently adopting postures in a range between the two NSCLBP subgroups. For slumped sitting no differences were observed in the upper lumbar spinal angle ($p=0.36$), however interestingly AEP subjects adopted a significantly less flexed lower lumbar posture and greater anterior sacral tilt compared to both the FP and healthy groups ($p<0.001$). This indicates that when instructed to adopt heavily flexed spinal postures, the FP appear to habitually adopt these end range postures and have little difficulty in achieving end range, expressing an ability to operate in a similar range to healthy individuals. Conversely the AEP group demonstrates reluctance to move into end range flexion lumbo-pelvic postures. This may be due to hyperactivity of the lumbar extensor musculature in this patient subgroup (O'Sullivan 2004). Similarly, both the control and AEP groups ($p<0.001$) displayed a greater change in upper lumbar angle between usual sitting and slumped sitting compared to the FP group. In the lower lumbar and sacral regions only the healthy group demonstrated a significantly greater change ($p<0.001$) between usual sitting and slumped sitting compared to both the FP and AEP groups. The FP group already appear to adopt end range flexed postures in usual sitting therefore the change in angle required to achieve slumped sitting may be minimal, however interpretation of the AEP results is less clear. It may be that the AEP group demonstrates smaller angular changes in the lower lumbar and sacral spinal regions when moving from usual to slumped sitting as the habitual hyperlordotic spinal posture hypothesised may arise predominantly from further up the spine e.g. the upper lumbar region. It is widely acknowledged that spinal segments do not operate in isolation, for example translations of the thoracic cage have previously been shown to significantly alter thoracic kyphosis, pelvis angle and lumbar curvature (Harrison et al. 2002), therefore it may be of value for the thoracic spinal region to also be considered as a factor in differentiating between NSCLBP subgroups using the MDCS.

Following MDCS implementation sample size was greatly reduced (AEP n=13, FP n=20) thus the extent to which these findings are generalizable to the wider NSCLBP population may be questionable. However the findings suggest that these subgroups may be a real phenomena to further support the validity of the CS (O'Sullivan 2005) and provide important considerations for future NSCLBP research. Regional differentiation between the upper and lower lumbar spinal regions appears to be important in differentiating between subgroups, thus regarding the lumbar spine as a single entity may be insufficiently sensitive to detect change.

These findings have been further replicated in a cycling cohort (Van Hoof et al. 2012). A significant increase ($p=0.018$) in lower lumbar spine flexion in cyclists with FP MCI (n=8) compared with 9 age and gender matched cyclists (no pain) was observed during a 2 hour outdoor cycling session. An associated significant increase in pain reported (Numerical Rating Scale (NRS)) over the 2-hour time

period ($p<0.001$) was also observed. The use of a high level cycling population, small sample size, and the highly flexed postures adopted during cycling tasks restricts the generalizability of the findings to the wider NSCLBP population as well as comparisons with usual lower-intensity functional activities. Methodological approaches between the studies differ with one using a BodyGuard™ posture monitoring system (Van Hoof et al. 2012) and the other using 3Space Fastrak® (Dankaerts et al. 2006b). It is also undetermined whether differences in other spinal regions exist between groups. However, these results support Dankaerts et al. (2006c) findings for the FP group and demonstrates that FP subjects appear to consistently adopt end range postures during prolonged postural activity, further supporting the proposed FP MCI subgroup (O'Sullivan 2005; O'Sullivan 2004).

The influence of age on spinal posture and pain should be considered with regard to NSCLBP subclassification. Experience of LBP during adolescence has been shown to be associated with LBP recurrence in adulthood (Brattberg 2004; Harreby et al. 1995) with CLBP prevalence reported to be as high as 8% in this population (Bejia et al. 2005; Salminen et al. 1999). Similarly to the adult population, the majority of instances are defined as 'non-specific' (O'Sullivan 2004). Astfalck et al (2010b) replicated Dankaerts et al. (2006c) methodology (and additionally evaluated total lumbar spine posture) in an adolescent cohort of 28 NSCLBP patients (14 female, 14 male, 14-16 years old) matched with 28 healthy control subjects for BMI, pubertal stage and socio-economic status. In agreement with Dankaerts et al. (2006c) sub-group differences in spinal angle were only identified when the NSCLBP group was subclassified. In usual sitting significant differences were observed in the AEP group compared to both the healthy and FP group for sacral angle ($p=0.001$) and total lumbar angle ($p=0.002$). In the upper lumbar region significant differences were observed between all 3 groups (FP, AEP, healthy). Similarly during slumped sitting the AEP group adopted significantly more lordotic postures in sacral ($p=0.004$), total lumbar (0.007) and upper lumbar (0.023) spinal regions. In contrast to Dankaerts et al. (2006c) no significant differences were observed in the lower lumbar region in either usual or slumped sitting. These findings suggest the AEP group to adopt postures most differentiated from healthy and FP individuals in sitting, presenting with greater lumbar lordosis. Since the methodological approach closely replicates Dankaerts et al's (2006c) work, it could be tenuously hypothesised that these differences were observed due to participant age (14-16 years). Although younger subjects may habitually adopt end range flexion or extension postures in the lower lumbar region they may be able to adapt spinal movement through range with greater proprioceptive awareness and plasticity of spinal motor control (Astfalck et al. 2010b). Older subjects may conversely display more established maladaptive behaviours and it has been suggested that changes in motor control may evolve with the disorder over time (Dankaerts and O'Sullivan 2011). In further support of this hypothesis no significant differences were observed in angular change between

usual and slumped sitting, with all groups moving through similar ranges of movement (Astfalck et al. 2010b).

Astfalck et al. (2010a) further evaluated lumbar and trunk sagittal spinal angles in sitting in adolescent NSCLBP subgroups (AEP, FP), which were calculated via sagittal photographs (reflective markers placed at C7, T12 and greater trochanter). Significant differences were observed in mean lumbar angle in the AEP group compared to both the FP and healthy groups ($p=0.001$). No significant differences were observed for trunk angle between NSCLBP subgroups, however, after adjustment for gender differences, the authors suggest there to be a likely reduction in mean trunk angle in the AEP group compared to the FP group, with the AEP group appearing to adopt a less kyphotic trunk angle. Although the authors state this is a method which has been shown to be reliable (Perry et al. 2008), it is unlikely to be as robust a method as 3D kinematic evaluation or electromagnetic methods thus the findings should be considered with caution.

Additionally, Astfalck et al. (2010a) observed healthy subjects to adopt more flexed usual sitting postures, therefore differences between the FP and control group may be minimal. This is further diluted by the small NSCLBP sub-group sample sizes (14 AEP, 14 FP) and the incorporation of multidirectional (MDP) MCI subjects into the FP group as 12 of the 14 flexion pattern subjects were classified as MDP. Consequently these subjects, although reporting flexion specific pain provocation may present with different physical attributes to FP subjects. These results are therefore incomparable with previous adult studies (Dankaerts et al. 2006a, c). In contrast to previous adult studies, the subjects investigated by Astfalck et al. (2010a) reported high levels of physical activity. In the symptomatic group 85.7% of subjects continued to take part in regular sporting activity despite 75% of the overall patient cohort reporting these activities as pain provoking. These findings, although interesting, may not be comparable with the wider adult LBP population.

Despite the small sample sizes employed across these studies (Astfalck et al. 2010a; Astfalck et al. 2010b; Dankaerts et al. 2006c; Van Hoof et al. 2012) significant between group differences were observed, suggesting the effect size to potentially be considerable between groups. Further work to investigate this phenomena in larger populations are however required. Interpretation of results of MDCS studies is further complicated by the influence of gender. Both Astfalck et al. (2010b) and Dankaerts et al. (2006c) observed a greater percentage of females classified as AEP (71.4% and 61.5% respectively) , in contrast the FP groups comprised proportionally more male subjects (78.6% and 80% respectively), creating difficulty when comparing NSCLBP subgroups to a single control group.

Having established distinct postural differences between FP and AEP subgroups in sitting (Astfalck et al. 2010b; Dankaerts et al. 2006c), ability to modify sitting posture specifically for subgroup presentations may be crucial to LBP management. O'Keeffe et al. (2013) explored direction specific seating modification and pain response in FP subjects (n=21) during a 1 hour typing task performed on a dynamic forward inclined chair and standard office chair. Low back discomfort (LBD) and overall body discomfort (OBD) were evaluated using the Body Part Discomfort Scale (BPDS) (Corlett and Bishop 1976). No significant differences in OBD were observed ($p=0.178$) between seating types, however LBD was significantly higher for the standard office chair ($p=0.005$) compared to the forward inclined chair. These findings suggest facilitation for FP subjects into greater anterior pelvic tilt may benefit these individuals by achieving a more neutral sitting posture. These preliminary results appear promising and could be incorporated within a targeted NSCLBP subgroup intervention, however no follow up sessions were conducted. It is therefore difficult to theorise whether seating modifications can influence carry-over (for longer-term pain management), or if individuals can achieve 'neutral' spinal postures independently on a standard office chair with education alone. Similar findings have been replicated in a small AEP population (n=12) reporting LBD and OBD (using the BPDS) during a 10 minute typing task whilst seated on either a standard or forward inclined seat pan (with and without a standard back rest) (Curran et al. 2014). LBD ($p<0.001$) and OBD ($p=0.016$) were significantly increased when the AEP subjects were seated on the forward-inclined seat pan, due to the increased lumbar lordosis posture perpetuated. The presence or absence of the backrest had no effect on trunk muscle activity or discomfort levels, indicating that pelvis angle of inclination appears to be the most influential factor for discomfort in sitting for AEP subjects. These results, when viewed in light of previous research into FP presentations (O'Keeffe et al. 2013), demonstrate that FP and AEP subjects demonstrate very different, direction dependent, pain provocative behaviours needing to be addressed using different intervention approaches. These studies (Curran et al. 2014; O'Keeffe et al. 2013) suggest direction specific MCI to be modifiable and respond to specific postural alterations.

Repositioning errors have been identified in AEP and FP subgroups in the thoracic spine (Sheeran et al. 2012) (as discussed in section 2.4.1.1), however, whether sagittal spinal posture differs in this spinal region during static postures or functional activities is currently unknown, thus future work on spinal kinematics should also incorporate evaluation of thoracic spine posture.

Spinal kinematics in AEP and FP subgroups have to date been evaluated only in static postures in a limited number of studies, however they provide evidence largely in support of the MDCS. These studies demonstrate the importance of subclassification in NSCLBP and provide insight into why interventions aimed at adapting posture, range of spinal movement or promoting movement into end range postures may not be beneficial for all patients, and in some instances may be mechanisms for

pain recurrence. Some discrepancies between adolescent and adult populations have been shown (Astfalck et al. 2010b) indicating that age may be an important factor for consideration when implementing the MDCS and designing novel subgroup interventions. These studies additionally highlight the importance of regional spinal analysis. To date, only two of the proposed MCI sub-groups of the MDCS have been evaluated within the literature (FP and AEP) with regard to spinal kinematics due to difficulties in recruiting sufficient subject numbers to explore FLSP, PEP and MDP MCI in detail. As FP and AEP subjects are the most commonly observed presentations it could be argued that, currently, there may be greater clinical need to more comprehensively understand the biomechanics of these MCI subgroups in order to develop effective treatment approaches, which could be beneficial for a significant proportion of the NSCLBP population. For this reason these subgroups will be the focus of this thesis, however evaluation of the other MCI subgroups remains a priority for future research.

2.3.3.5 Evaluation of Muscle Activity in MCI Subgroups

Trunk muscular dysfunction in NSCLBP is poorly understood with substantial variability reported in the literature, despite being regarded as a key feature of NSCLBP. During static postures studies have reported increases (Arena et al. 1991), decreases (Ahern et al. 1988; Cassisi et al. 1993) and no change in muscle activity (Ahern et al. 1988; Kravitz et al. 1981) in NSCLBP cohorts compared to healthy subjects. These inconsistences highlight the heterogeneous nature of NSCLBP and emphasise the need for robust classification approaches to identify homogeneous subgroups.

Dankaerts et al (2006a) evaluated trunk muscle activity in NSCLBP (pooled and subgrouped according to the MDCS) in sitting using a previously investigated patient cohort (Dankaerts et al. 2006c). Five muscle groups were evaluated using surface electromyography (sEMG): Rectus Abdominis (RA), External Oblique (EO), Transverse fibers of internal oblique (TrIO), sLM and Iliocostalis lumborum pars thoracis (ICLT). No significant differences in muscle activity were identified between the healthy group and the pooled NSCLBP group during usual sitting, however in slumped sitting a significant increase in extensor muscle activity was observed in the pooled NSCLBP group. Significant differences were importantly observed following NSCLBP subclassification with AEP demonstrating significantly increased activity in extensor musculature (sLM, ICLT) and TrIO compared to the healthy and FP groups in slumped (sLM $p<0.003$, ICLT $p<0.001$, TrIO $p=0.009$) and usual sitting (sLM $p=0.006$, ICLT $p<0.001$, TrIO $p=0.019$). No differences were observed for EO or RA in either condition. Differences in muscle activity during usual sitting were only evident after subgroups had been established, further validating the MDCS. NSCLBP sample size (as discussed previously) was small (FP n=20, AEP n=13) thus a larger population may be required to establish

distinct muscle activity trends. As discussed in section 2.6.2 the use of sEMG of the trunk muscles demonstrates variable reliability, however significant differences were still observed. AEP individuals appear to demonstrate increased activity of TrIO, sLM and ICLT during both usual sitting and slumped sitting, concurring with the MDCS that the AEP subgroup clinically demonstrate spinal musculature hyperactivity which may predispose the individual to increased spinal loading (O'Sullivan 2004). When considered in conjunction with Dankaerts et al. (2006c) observation of increased lordosis in the AEP subgroup it becomes apparent that these patients may present with defined physical spinal characteristics alongside a subjective reporting of extension biased pain. However, why individuals adopt such pain provocative maladaptive patterns and behaviours is unclear (Dankaerts et al. 2006a). These postures have been observed for some time (Kendall et al. 1952) therefore it may be that these are habitual postures for the individual which are continued (or exaggerated) in the presence of pain.

Sheeran et al. (2012) were unable to replicate Dankaerts et al (2006a) observations. Evaluation of bilateral sLM, ICLT, EO and the transverse fibers of internal oblique (TrIO) muscle activity (sEMG) in FP and AEP subjects (n=51, n=39 respectively) and healthy subjects revealed no differences in usual sitting in ICLT or sLM. Conversely differences were identified in EO and TrIO between the pooled NSCLBP and healthy controls (EO p=0.001, TrIO p=0.004) and both subgroups when compared with the control group (EO p=0.002, TrIO p=0.006). These findings were replicated in standing postures, with sLM additionally demonstrating significantly increased activity in the FP group compared with the control group. No differences were observed between the FP and AEP subgroups. Conflict with the data of Dankaerts et al (2006a) may be due to analytical differences in sEMG as Dankaerts et al (2006a) reported unilateral (left sided) sEMG amplitudes whereas Sheeran et al. (2012) calculated a combined bilateral average sEMG amplitude. Both these studies evaluated static postures thus comparison to dynamic activity may also explain such conflictions.

Muscle activity has also been observed to be poor at discriminating between subgroups when the MDCS is applied to an adolescent population. In contrast to Dankaerts et al. (2006a), Astfalck et al (2010b) observed no significant differences in usual or slumped sitting with the exception of increased IO activity in the healthy group (p=0.034) compared with the pooled NSCLBP group. Differences between study outcomes may be attributable to the age of the subjects tested (14-16 years old) as spinal immaturity and a potentially enhanced plasticity of spinal motor control, in comparison to older patient cohorts, may be a contributory factor (Astfalck et al. 2010b).

Further, Curran et al. (2014) similarly identified no consistent changes or patterns of activity in trunk muscle activity (sLM, ICLT and EO) in a cross-over study evaluating 12 AEP subjects during a 10 minute typing task seated on a standard or forward-inclined seat pan (with and without a standard

back rest). Despite significant differences in LBD and OBD (detailed in section 2.3.3.4) no significant differences in muscle activity were noted in muscle activity ($p>0.05$).

Muscle activity as outlined by these studies (Astfalck et al. 2010b; Curran et al. 2014; Dankaerts et al. 2006a; Sheeran et al. 2012), measured using sEMG, may not be sufficiently sensitive for discerning subgroup differences, especially during static postures. Future work should evaluate muscle activity in more dynamic functional tasks (e.g. reaching, lifting, bending), where differences in muscle activity may be more pronounced to determine if subgroup differences are observed.

Despite a lack of consensus within the literature, muscle activity parameters, when considered alongside spinal kinematics, have been shown to accurately identify clinical characteristics of the MDCS. Dankaerts et al (2009) developed a statistical classification model to determine whether MDCS subgroups (FP, AEP) and healthy individuals could be derived from the laboratory results for muscle activity and spinal kinematics during standing, forward bending and return, backward bending, usual sitting and slumped sitting. Inputs included all parameters previously demonstrating significant between group differences (Dankaerts et al. 2006a, c) including: sacral angle, lower lumbar and total lumbar spinal angle, and sEMG of ICLT, TrIO and sLM, to create a statistical model to compare with clinical subclassification (using MDCS). The statistical model correctly identified 96.4% of classifications to further validate the MDCS and suggest that lumbar kinematics and hyperactivity of sLM, ICLT and TrIO may be key subgroup discriminators that can be accurately determined through clinical assessment (Dankaerts and O'Sullivan 2011).

In summary there appears to be some inconsistency in the pattern of muscle activity within the MDCS in either adult or adolescent cohorts which may be indicative of poor sEMG reliability (as discussed in section 2.6.2) or due to heterogeneity of muscle activity present within the subgroup classifications, as has been previously reflected in inconsistencies observed in the wider NSCLBP population (Ahern et al. 1988; Arena et al. 1991; Cassisi et al. 1993; Kravitz et al. 1981). To date, muscle activity in individuals subclassified using the MDCS has only been explored in static postures and spinal ROM tasks. Dynamic activity evaluation of muscle activity may therefore be warranted to establish between group differences in muscle activity and therefore analysis of muscle activity during functional activity is a core focus of this thesis.

2.3.3.6 Classification Based Cognitive Functional Therapy

A strength of the MDCS is the proposed framework for targeted management intervention using classification-based cognitive functional therapy, however since the MDCS has been developed

clinically, and has to date only been primarily validated in static postures, the functional applicability of the subclassification approach is yet unknown. Classification based cognitive functional therapy (CB-CFT) is designed to address both the physical factors and cognitive drivers of pain with a view to resolution, or long-term management, of the disorder (O'Sullivan 2005). CB-CFT has four key components: 1) cognitive, patient education outlining the mechanisms for the pain; 2) direction specific movement exercise, to normalise maladaptive behaviours; 3) functional integration (involving activities reported by the patient to be pain provocative); and 4) home exercise physical activity programme (specific to the classification / impairment) (Fersum et al. 2013).

Case studies of individuals presenting with MCI have shown that interventions focussed around motor learning and cognitive functional therapy can be beneficial in optimising posture and lumbo-pelvic kinematics and improving reported disability, pain and fear of movement (Cañeiro et al. 2013; Dankaerts et al. 2007; Van Hoof et al. 2011). Although the inherent limitations of inferring clinical application from case studies alone is acknowledged, these study results are encouraging, suggesting MCI disorders demonstrate potentially reversible physical characteristics and improvements in PROMs following targeted MLI.

Sheeran et al. (2013) evaluated response to classification-guided intervention (CGI) (compared to generalised postural intervention (GPI)) in a pragmatic RCT in AEP and FP subgroups. Similarly to previous case studies (Cañeiro et al. 2013; Dankaerts et al. 2007; Van Hoof et al. 2011) significant post-intervention reductions in disability, pain were identified for the CGI compared to the GPI group. Individuals in the CGI group also demonstrated significantly reduced AE in the thoracic spine during sitting and in the lumbar spine during standing. It is a finding of interest that changes can be obtained, and in some instances maintained over a longer time period utilising the MDCS with minimal clinical input required for intervention. This further supports the suggestion that these MCI disorders are modifiable factors which targeted, classification guided intervention can address (Dankaerts and O'Sullivan 2011).

Fersum et al. (2013) conducted an RCT comparing CB-CFT with manual therapy and exercise intervention (MT-EX) in subclassified NSCLBP (using MDCS). All subgroups (AEP, FP, FLSP, PEP and MDP) and both movement and motor control impairment subjects were included in the study with CB-CFT individualised to each classification with NSCLBP (n=121) patients randomised to either CB-CFT (n=51) or MT-EX (n=43). CB-CFT demonstrated superior outcomes compared to MT-EX immediately and at 12 months with significant improvements in disability (ODQ) ($p < 0.001$) and pain (NRS) ($p < 0.001$) (although MT-EX pain score were still significantly improved post-intervention ($p < 0.001$)). Greater improvements in anxiety and depression scores (Hopkins Symptoms Checklist), fear avoidance (Fear-Avoidance Beliefs Questionnaire), patient satisfaction,

work absenteeism and care seeking were all consistently observed in the CB-CFT group compared to the MT-EX group. A major clinical consideration is the time required for clinician training in the approach with each clinician (for CB-CFT) undertaking approximately 106 hours training. This is unlikely to be feasible for most practitioners, especially those working in publically funded health services with finite time and finance resources. Future work evaluating CB-CFT with respect to service delivery in a more cost effective manner (e.g. group based interventions) may prove a more effective approach to treatment in the patient population.

2.3.3.7 Summary

Subclassification appears to be key to identifying homogeneous subgroups within heterogeneous NSCLBP and MCI subgroups appear to be a real phenomenon. Distinct differences in spinal kinematics have been observed with regard to lumbar spine posture in sitting (Astfalck et al. 2010b; Dankaerts et al. 2006c). Additionally direction of repositioning error has been identified to differ between FP and AEP groups in both the thoracic and lumbar spinal regions in both sitting and standing (as discussed in section 2.4.1.1) (Sheeran et al. 2012). The majority of the MDCS evidence base currently has been explored in sitting postures, however patients report pain during a variety of functional activities which needs to be explored in future work. Consensus on differentiation in trunk muscle activity between MCI FP and AEP groups is inconclusive throughout the literature (Astfalck et al. 2010b; Curran et al. 2014; Dankaerts et al. 2006a; Sheeran et al. 2012). This may be due to the static nature of the postures investigated with resting muscle activity insufficiently challenging enough to demonstrate significant between group differences. Pain is likely to influence performance of dynamic, functional activities in NSCLBP (Shum et al. 2005b, 2007a), thus future research investigating trunk muscle activity during more dynamic tasks is warranted to explore MCI subgroup differences. It also appears that adolescent NSCLBP MCI subgroups present with contrasting physical attributes (Astfalck et al. 2013; Astfalck et al. 2010a; Astfalck et al. 2010b) therefore future work investigating the MDCS should consider adult and adolescent cohorts independently.

A limitation of the current evidence base for the MDCS approach is that a substantial volume of supporting literature has been conducted by a primary research team, often inclusive of the MDCS developer (O'Sullivan), thus studies performed independently of the core research team is required to eliminate the potential for bias, especially in consideration of clinical patient assessment for clinical trials.

Although CB-CFT has been shown to enhance patient outcome compared with usual care, improvements in clinical outcomes may only be observed when the classification approach is robust

and valid. Initial findings from studies published to date exploring the MDCS are encouraging in support of subgroup attributes, especially with regard to the response to CB-CFT (Fersum et al. 2013), however current work evaluating subgroup biomechanical presentations has been mainly limited to static postures alone in small cohort samples thus is quite limited in depth and breadth. The extent to which these characteristics are expressed in the wider subgroup populations during a range of activities is yet to be explored. A core aspect of this approach is the re-education of functional movement. Although targeted interventions have been developed for the MDCS the baseline understanding of spinal movement during functional activity has not been established.

NSCLBP MCI subclassified using the MDCS appear to be a real phenomenon within this patient population however further work investigating spinal kinematics and trunk muscle activity during functional tasks is warranted to obtain a clear understanding of how specific functional re-education strategies can be beneficial for long term pain management and resolution in NSCLBP and further inform and refine CB-CFT strategies.

2.4 Motor Control Impairments of the Spine

2.4.1 Pain and Motor Control

The relationship between pain and motor control is not fully understood within scientific literature (Dankaerts and O'Sullivan 2011; Hodges 2011; Hodges and Moseley 2003; van Dieën et al. 2013). Key questions remain: do sub-optimal motor control strategies lead to pain provocation? Or alternatively, does pain preclude adaptive changes in motor control? In support of the latter, Hodges et al. (2013) showed spinal stability and trunk muscle activity to increase in the presence of experimentally induced pain in healthy individuals. It is suggested that acute LBP increases spinal stability as an individualised response to pain. Although this 'stabilising' strategy may be beneficial short-term, it appears that pain may preclude alterations in motor control which could be a factor for chronic pain provocation.

There is widespread consensus of MCI as a mechanism for NSCLBP, however the mechanisms driving these MCIs and their impact on subsequent motor planning has been theorized to manifest itself in multiple ways throughout the literature (Biedermann et al. 1991; Hodges 2001; Hodges 2011; Luoto et al. 1999; van Dieën et al. 2013). Motor control of the spine is achieved through a complex integration of the active (muscular), passive (osseoligamentous structures e.g. vertebrae, discs and ligaments) and neural (peripheral and central nervous system) control systems, where dysfunction to one of the systems may either lead to an immediate compensation of another subsystem (normal

functional response), an adaptive response of another system long-term (causing altered spinal stability) or a potential injury to another system, causing system dysfunction (i.e. LBP) (Panjabi 1992b).

A number of factors have been proposed to influence motor control. Movement control is dependent on accurate sensory information, thus changes in afferent mediated control (proprioception) may influence motor control of the spine. Proprioception, balance and sensory factors have been shown to be impaired in CLBP (Hodges and Moseley 2003; Silfies et al. 2009a), with reduced sensory input to the spine demonstrated to reduce acuity in CLBP (Gill and Callaghan 1998) as well as consistently being shown to decrease the individual's ability to reposition the spine (Brumagne et al. 2000). This concept has been explored in MDCS subgroups where increased repositioning error in NSCLBP subgroups (FP and AEP) has been observed (Astfalck et al. 2013; O'Sullivan et al. 2013b; Sheeran et al. 2012). A reduction in reaction time has also been observed in CLBP populations (Luoto et al. 1995a; Taimela and Kujala 1992) indicating sensory and proprioceptive factors to directly influence motor control dysfunction and pain. Furthermore, cortical effects, for example changes in the central nervous system activity as a result of stress or fear, may lead to developments of motor control impairments in the presence of pain (Hodges and Moseley 2003).

Pain has been proposed to significantly alter motor control patterning via changes in spinal cord and cortical excitability (Hodges and Moseley 2003). It has been suggested that individuals who have had previous exposure to spinal pain may develop compensatory, adaptive movements to avoid pain provocation (Hodges and Moseley 2003; van Dieën et al. 2003), which, as suggested by O'Sullivan (2005) may become maladaptive causing subsequent chronic pain provocation. Panjabi (1992a) proposed a model to explain a potential mechanism for pain, whereby sub-optimal motor control strategies preclude reduced joint control of movement which hence leads to abnormalities in loading, creating micro trauma and resulting in pain provocation. Multiple models of motor control adaptations as a result of pain have been proposed, such as the "vicious cycle" model (or "Pain-Spasm-Pain" model) (Roland 1986), and the "Pain-adaptation model" (Lund et al. 1991). Acutely induced experimental pain has been shown to cause changes in spinal motorneuron activity (Matre et al. 1998; Svensson et al. 1998; Svensson et al. 2000). However this has been disputed by other studies which have found no changes in motorneuron or motor cortex excitability in the presence of pain (Gandevia et al. 1996). These studies have been conducted on acute experimental pain, therefore changes in spinal motorneuron activity over a prolonged time period (i.e. chronic pain) cannot be determined through this methodological approach.

CLBP subjects have also been shown to demonstrate slower reaction times compared to healthy control subjects suggesting impairments in information processing are an attribute in this patient

group (Luoto et al. 1995b; Taimela et al. 1993). It is unclear whether slow reaction times may be a contributory factor to the development of CLBP, or slower reaction times occur as a result of pain (alongside other potential influences such as depression, anxiety or fear responses). Impaired reaction times have been shown to improve following rehabilitation (Luoto et al. 1996; Luoto et al. 1999), which suggests that slow reaction times may a consequence of CLBP rather than a causative factor.

Another factor for consideration is variability of movement. Variability is a key principle in the study of movement and posture and is central to normal motor learning and control (Moseley and Hodges 2006). Hodges et al. (2013) evaluated spine stability (using an EMG driven model) and net trunk muscle activity in 17 healthy individuals in the presence and absence of experimentally induced pain during flexion and extension tasks. Both the stability index ($p<0.017$) and net muscle activity ($p<0.0.021$) increased in the presence of pain however no two participants displayed similar patterns of behaviour. This suggests that movement strategies in response to pain may be unique to each individual.

These observations support previous work evaluating variability of postural strategy (Moseley and Hodges 2006; Moseley et al. 2004). Moseley and Hodges (2006) observed that subjects for whom pain caused a reduction in postural strategy variability did not return to normal on cessation of pain, indicating that potentially protective postural strategies are adopted when individuals have an expectation of pain, as previously demonstrated by Moseley et al. (2004). This may explain why individuals with recurrent back pain display these postural invariabilities despite current absence of pain (Hodges and Richardson 1996).

2.4.1.1 Spinal Position Sense

Reductions in the proprioceptive awareness of spinal position can ultimately predispose the spine to adopt compensatory strategies, and altered motor control patterns, in an attempt to enhance the dynamic stability of the spine in CLBP populations (Silfies et al. 2009a), potentially predisposing individuals to adopt end range spinal postures (Burnett et al. 2004; O'Sullivan et al. 2003).

Differences in SPS have been observed in MDCS MCI subgroups. Sheeran et al. (2012) evaluated identified that NSCLBP subjects demonstrated a significant increase in absolute error (AE) (magnitude) and variable error (VE) (variability) compared to the healthy group in sitting and standing in both the lumbar and thoracic spine, however no differences in constant error (CE) were identified. When subgrouped, differences between the AEP and FP groups were identified in both the thoracic ($p=0.001$) and lumbar spine ($p=0.003$) with the FP group underestimating the lumbar and

overestimating the thoracic spinal target compared to the AEP and control groups. The AEP group conversely overestimated the lumbar and underestimated the thoracic spinal target compared to the FP group ($p<0.016$). In standing differences were only observed in the AEP group (compared to the healthy group) in the lumbar spine with regard to CE, with the AEP group significantly overestimating the target Lx angle ($p<0.016$). MDCS subgroups thus appear to exhibit distinct between group (FP and AEP) differences in direction of error, especially in sitting, further highlighting the presence of directional preference as proposed by the MDCS (O'Sullivan 2005) and further parameters of homogeneity for FP and AEP subgroups. There is much debate regarding 'optimal' neutral sitting posture (Claus et al. 2009b; Dankaerts et al. 2009; O'Sullivan et al. 2010; Pynt et al. 2001), as repeatability will be influenced by tester interpretation of 'neutral' spine posture, which may have influenced these findings. However, it is also important to note the novel parameters explored in the Sheeran et al. (2012) study, which were evaluation of the thoracic spine, and evaluation of standing posture, neither of which have previously been investigated and in both of which significant differences were observed.

Lumbar spine repositioning error has also been evaluated in FP individuals compared with healthy subjects in sitting through reproduction of a lumbar target position after 5 seconds of slumped sitting (O'Sullivan et al. 2013b). Similarly to Sheeran et al. (2012), significant increases in AE ($p<0.002$) and CE ($p<0.006$) in the FP (NSCLBP) group were noted, with the FP group underestimating the lumbar target position. However, in contrast to Sheeran et al. (2012), O'Sullivan et al. (2013b) observed no differences in VE ($p<0.165$). These findings support previous work by Sheeran et al. (2012) that motor control and proprioceptive deficits are apparent in these patient subgroups with the FP group appearing to consistently underestimate neutral lumbar spine angle. This provides further support for the rationale that these patients habitually adopt end range pain provocative spinal postures with little conscious awareness.

It is clear that many different factors influence MCI in NSCLBP. Spinal position sense has been shown to be compromised in NSCLBP subjects subclassified according to the MDCS with direction-specific repositioning errors consistently observed in adult subjects. Proprioceptive deficit may also be a contributory factor to the adoption of end range, pain provocative postures. Although established differences have been observed in sitting and standing in MDCS MCI subgroups, it is hypothesized that these individuals may maintain pain provocative end-range postures throughout daily functional activities, however this has not been established to date.

2.5 Spinal Biomechanics: Differences between NSCLBP and Healthy Individuals

2.5.1 Spinal Kinematics

2.5.1.1 Static Postures

Sitting is reported to be one of the most commonly reported aggravating postures for LBP (Dankaerts et al. 2006c; Vergara and Page 2002; Womersley and May 2006), however, the relationship between prolonged sitting postures and low back pain is not fully understood with some studies suggesting that sitting and prolonged standing are not associated with LBP onset (Bakker et al. 2009; Roffey et al.). Lis et al. (2007) found that although sitting alone did not increase LBP onset risk, adopting 'awkward' spinal postures was associated with back pain. It is likely that avoidance of pain provocative sitting postures, especially end range spinal postures as demonstrated by the FP and AEP subgroups, may be beneficial for a significant proportion of NSCLBP patients (Curran et al. 2014; O'Keeffe et al. 2013). Although there is no clear consensus on 'optimal' spinal posture (O'Sullivan et al. 2012a), both clinicians (O'Sullivan et al. 2012a) and the wider public (O'Sullivan et al. 2013a) have been shown to perceive lordotic lumbar sitting postures to be most 'optimal'.

Habitual sitting posture has been compared to postures which therapists perceive to be 'optimal' in a healthy cohort (n=17) (O'Sullivan et al. 2010). Habitual sitting posture (HSP) was compared with the subjects' subjectively perceived ideal posture (SPIP) and a therapist perceived neutral posture (TPNP). TPNP was repeated by two inexperienced, and blinded, therapists who had undergone identical training in neutral spine repositioning in sitting. Although the authors address the reliability of TPNP being implemented through identical training, no clear consensus regarding 'optimal neutral sitting posture' has been previously established in the literature (O'Sullivan et al. 2012a). Thus the study may be open to researcher bias through their own perceived 'optimal neutral postures', however neutral spine posture was defined as a 'slight lumbar lordosis and relaxed thorax' (O'Sullivan et al. 2006a). TPNP was found to have a high ICC (0.91 95% CI) repeatability between testers. Lower lumbar posture was found to be significantly more flexed in the HSP compared to the TPNP and SPIP postures ($p<0.05$), thus it appears that although habitually healthy individuals appear to adopt 'slumped' spinal postures they have the ability to vary their posture and can be reliably positioned into neutral spinal postures (when both therapist positioned and self- guided). However, the use of two 'inexperienced' clinicians trained to deliver a prescribed posture may not reflect neutral posture selection delivered by experienced clinicians without guidance.

O'Sullivan et al. (2006b) observed differences in spinal-pelvic curvature in sitting postures in a small (n=22) healthy cohort. Subjects were instructed to adopt upright 'thoracic', upright 'lumbo-pelvic' and slump sitting postures, evaluated using a 3Space Fastrak® system. A significant increase in thoracic extension ($p<0.001$) and decrease in lumbar extension ($p<0.001$) and anterior pelvic tilt ($p=0.03$) was noted in the thoracic upright sitting group compared to upright lumbo-pelvic sitting. In comparison to slump sitting, both thoracic and lumbar upright sitting involved significantly greater thoracic and lumbar extension and anterior pelvic tilt ($p<0.001$), demonstrating that healthy subjects are able to adopt differing postures with unique kinematic characteristics in the absence of pain. The findings also provide some support for upright lumbo-pelvic sitting as an 'optimal' spinal posture as it appears to involve no extreme end range positions. Interestingly this study also identified specific differences in muscle activity in each sitting posture, the results of which are discussed in section 2.5.2.3. Thoracic curvature in this study was calculated as the curvature between the levels of T6 and T12, thus the behaviour of the 'total thoracic' spinal region is unable to be evaluated. How the upper thoracic spinal region responds to changes in posture in healthy individuals is undetermined. However, consideration of these regional spinal changes in healthy individuals provides baseline comparisons for future studies evaluating postural maladaptive changes in NSCLBP individuals.

These studies provide insight into sitting postural behaviour in healthy individuals, however how these postures vary in the presence of pain is a key question for NCLBP research. Bell (2008) investigated low back pain incidence in a cohort of sedentary workers. A fibreoptic goniometer system continuously recorded lumbar spine and hip movement throughout the working day to identify that workers spent on average 86% of the working day sitting, of which only 26% was in a lordotic lumbar spine posture. Similarly to O'Sullivan et al (2010), subjects tended to adopt more flexed sitting postures, however kyphotic lumbar sitting posture was found to be indicative of current acute back pain (lasting less than 24 hours) in this cohort. These findings are in direct contrast to other literature showing lordotic lumbar posture to be associated with increased discomfort in sitting (Bennett et al. 1989; Vergara and Page 2002). Interestingly, kyphotic spinal posture was not found to be an indicator for ongoing back pain at six months, although limited variation in lumbar movement during sitting was found to increase the risk of development of chronic pain. This limitation in spinal movement variability may be an important factor for CLBP development, occurring either as a result of, or leading to, maladaptive movement strategies and changes in spinal proprioception and sensory feedback as noted by Moseley and Hodges (2006) (previously discussed in section 2.4.1).

Regional spinal evaluation may be a factor for consideration in determining differences between NSCLBP individuals and healthy individuals. This has been established in sitting in the lumbar spine in a student nursing cohort (Mitchell et al. 2008). No correlation between upper and lower lumbar spinal angles was identified in sitting postures (p=0.638), however upper lumbar spinal angle was

found to be inversely correlated with mean lower lumbar spinal angle in standing ($p<0.001$). Interesting, these results suggest that consideration of regional spinal angles (i.e. upper and lower lumbar spine, as opposed to total lumbar spine) may be required in future research to more accurately report and differentiate spinal posture. It is however difficult to interpret these findings as a student nursing cohort will exhibit varying degrees of low back pain, from asymptomatic to severe LBP thus introducing heterogeneity into the study population. The authors acknowledge this as a confounding variable and subgroup the subjects according to presence of LBP and severity, however no results for usual standing or sitting are reported in relation to LBP severity.

Standing postures have also been explored to evaluate differences in habitual standing posture between LBP and healthy subjects, although little research exists to explore variation in sagittal spinal posture during prolonged standing (Jackson et al. 2000). Laird et al. (2014) suggest that lordosis is not a differentiating factor between LBP and healthy subjects in a review of 8 identified articles (Christie et al. 1995; Day et al. 1984; Hultman et al. 1993; Ng et al. 2002a; Norton et al. 2004; Nourbakhsh et al. 2001; Waddell et al. 1992; Youdas et al. 2000). However it could be argued that this may be due to the heterogeneous nature of the LBP groups investigated. Substantial variability in both the LBP and healthy groups were observed (LBP=23-56°; Healthy=19-53°) which may be explained by the variety of measurement approaches used, but also may be reflective of concealed subgroups as NSCLBP subgroups may demonstrate opposing end range habitual postures in sitting (Dankaerts et al. 2006c).

Changes in sagittal lumbar and pelvic alignment have been investigated during sitting and standing in a cohort of healthy adults (n=50) (Endo et al. 2012) using lateral radiographs to analyse lumbar lordotic angle (LLA). Changes in LLA from sitting to standing were observed to be -16.6° (-49.8%, $p<0.01$), indicating that healthy individuals adopt significantly less lordosis in the lumbar spine during sitting. Whether this same trend occurs in individuals with low back pain is unknown and an area for further exploration. Another finding of interest was the observation that females adopted sitting postures with increased LLA in compared to males. This is of note as the MDCS (O'Sullivan 2005) appears to indicate clinically that a greater proportion of the NSCLBP population fitting AEP criteria tend to be women, with males proportionally more likely to be FP. This is a consideration when interpreting results for any classification guided protocol as gender differences may be a factor.

Another radiographic study of 100 LBP and 100 healthy subjects identified that LBP subjects display differences in spinal segmental lordosis during standing compared to healthy individuals, with the overall degree of total lordosis being observed to be lower in the LBP group (Jackson and McManus 1994). Two thirds of the total lumbar lordosis observed across all individuals was found to be displayed at the L4-5 and the L5-S1 levels, however, interestingly, the symptomatic group tended to adopt postures with less distal lordosis but greater proximal lumbar lordosis (Jackson and McManus

1994) indicating that these patients appear to adopt different postural strategies to pain-free subjects in standing. Radiological evaluation of spinal posture, although considered to be the 'gold standard', is limited as only 2D movement can be evaluated, and the degree to which radiological findings reflect 'habitual posture' in an artificial environment could be questioned. Although this approach does not subclassify subjects according to postural presentation, the results suggest that pain may alter postural behaviour in the spine during standing. It also highlights the requirement for upper and lower lumbar regions to be separately evaluated in postural spinal kinematics as there appear to be differences in postural, and potentially movement, strategies between LBP and healthy subjects.

2.5.1.2 Range of Movement

ROM of the lumbar spine has been suggested to be of clinical importance in identifying symptomatic individuals (Ping et al. 2005), where aggravated spinal tissues as a result of poor spinal biomechanics become the primary pain mechanism (Zhao and Feng 1996). Due to the difficulties encountered in accurately measuring in vivo spinal movement, which are outlined in section 2.6.1, to date few studies have managed to fully characterise spinal movement through range.

Mitchell et al. (2008) identified total lumbar ROM, measured as the difference between maximum lumbar flexion and extension in standing, to be approximately 96° in a cohort of 170 nursing students. Interestingly, the contribution of the lower lumbar angle to this overall movement was reported to be 58%, as opposed to 42% in the upper lumbar region, which highlights the importance of regional kinematic analysis. It may therefore be insufficient to consider the lumbar spine as a total entity in order to establish between group differences. It is acknowledged by the authors that this cohort is highly heterogeneous as nursing students will present with a spectrum of reported LBP symptoms (No Pain, Mild Pain and Significant Pain) thus these results are difficult to interpret in isolation. The authors found that overall ROM was reduced in the Significant Pain group compared to the No-pain (-3.7°, 95%CI: -6.3° to -1.0°) and Mild Pain (-3.1°, 95%CI: -5.3° to -1.0°) groups, however ROM of the total lumbar spine region during backward bending was found to be the only significantly different measure between the groups ($F=5.18$, $p=0.007$). Although it appears that pain may have some impact on ROM, this finding is inconsistent throughout the literature. The use of a large cohort (n=107) is a strength of the study, however all subjects were female. It has been shown previously that females adopt significantly less flexed lumbar postures compared to males (healthy student cohort) (Dunk and Callaghan 2005) thus these findings are likely not to be reflective of the male population.

Esola et al. (1996) investigated lumbar and hip motion during a full forward bending task in 20 individuals with a history of LBP and 21 individuals without (23-46 years old), using a 3D

optoelectronic motion analysis system. The results suggested that individuals with LBP tended to utilise a similar range of lumbar spine movement compared with healthy individuals, however the pattern of motion differed with the LBP group tending to utilise greater range of lumbar movement during the earlier period of forward flexion. Significant differences were also observed with regard to the lumbar-to-hip ratio, which was significantly lower during the mid-portion of the flexion movement in the LBP group ($p<0.01$). In this study lumbar range was calculated as a single measure between T12/L1 and S2 to give an overall indication of spinal range as opposed to spinal curvature. Thus how spinal curvature changes through range in relation to pelvis position may be of interest in future research. Many activities of daily living are performed in slight or mid range forward bending postures (for example ironing, washing hands, etc.), thus these findings are of particular interest as it may be that individuals with pain operate primarily through the lumbar spine in these ranges of movement, rather than utilising hip movement, thus increasing biomechanical stress through the lumbar region (Esola et al. 1996).

Similarly, Burton et al. (1989) explored lumbar spine sagittal mobility during full flexion and extension in 958 subjects (216 school children, 742 adults), age 10-84 years, where the level of LBP was determined through the use of a questionnaire to establish whether the individual had either 'no', 'previous history of' or 'current' LBP. A flexicurve device determined maximum lumbar mobility by recording the midline spinal contour between T12, L4 and S2. This technique has been previously reported to have moderate repeatability (9% intra-operator and 15% inter-operator variability) (Burton 1986). Mobility was shown to be reduced in adults with a history of (or current) LBP, which is in direct conflict with the findings of Esola et al. (1996). This may be due in part to the difference in larger age range of the subjects in this study (10-84 years compared to 23-46 years). In support of this assumption, the authors report that, following regression analyses, it was demonstrated that both age and gender accounted for ⅓ of mobility variation with LBP (current or previous) accounting for only an additional 1%. Additionally it may be that the difference in methodological approach (flexicurve as opposed to 3D optoelectronic motion analysis) may account for some variation. Interestingly, the authors found that reduced mobility was more apparent in the upper lumbar spinal region in the LBP (current and previous) individuals, when compared with healthy subjects. This is reflective of findings of differences in mobility in this region as observed previously in subgroups of NSCLBP in static sitting postures (Astfalck et al. 2010b; Dankaerts et al. 2006c). A further finding was that subjects with a previous history of (but not current) LBP, especially younger adult male subjects, tended to not achieve mobility levels comparable with healthy subjects despite currently being pain free (Burton et al. 1989). This indicates that on resolution of symptoms biomechanical changes in spinal movement are present, which may predispose an individual to further acute pain onsets. It is difficult to establish clear differences in sagittal lumbar mobility between LBP and healthy individuals from these study findings, due to the omission of a clear subclassification strategy. LBP experience was recorded

purely on the basis of responses to researcher derived questions thus the groups are likely to have been highly heterogeneous.

The presence of pain at end range is debated throughout the literature, with repeated end range movement patterns shown to be both beneficial and potentially aggravating in individuals with NSCLBP (Donelson et al. 1991). End-range repeated extension in standing has been shown to significantly reduce pain intensity whereas repeated flexion was shown to significantly increase pain intensity and peripheralise symptoms in a large NSCLBP cohort (n=145) (Donelson et al. 1991). Individuals also appeared to demonstrate directional preferences (40% extension preference, 7% flexion preference) with only one subject reporting pain relief in both end-range flexion and extension. These findings are interesting as they suggest a link between end-range pain provocation and the potential presence of distinct subgroups linked to these directional preferences. Burton et al. (1989) also explored the influence of hypo- and hyper- mobility and established that at end range flexion and extension both hypo- and hyper- mobility indicated a potential risk factor for LBP. This is a concept explored through the MDCS with extreme end range postures proposed to be adopted by the AEP and FP subgroups (O'Sullivan 2005). However Burton et al. (1989) report similar levels of hypo- and hyper- mobility being observed in some individuals across all groups. These results tend to suggest that pain may not be directly linked to levels of 'mobility' in the spine but by other mechanisms such as altered motor control. Alternatively it could indicate that the LBP group investigated is highly heterogeneous and thus conceals a number of LBP presentations, which blur the understanding of specific pain mechanisms.

It appears that the biomechanics of full ROM with regard to flexion and extension of the spine are not currently fully understood. The difficulties in reporting full range of motion in LBP, especially in reporting ROM relative to healthy controls may be in part due to the heterogeneity of NSCLBP, with multiple homogeneous subgroups operating through full ROM in different patterns of motion. Evaluating ROM in subclassified MCI subgroups, compared to healthy control subjects, may enable NSCLBP disorders to be better understood. It is clear however that regional differentiation through ROM is important as distinct differences have been demonstrated in the upper and lower lumbar spinal regions (Mitchell et al. 2008).

2.5.1.3 Functional Activities

Although spinal ROM can provide insight into patient movement behaviour, any maladaptive postural strategy is likely to carry over into functional activity performance, as observed in acute, sub-acute (Verbunt et al. 2005) and chronic LBP (Spenkelink et al. 2002). Thus limited capacity to perform, and pain during, everyday activities may become bothersome for patients. NSCLBP patients may present

with altered functional adaptive strategies during everyday activities when compared to the functional movement patterns exhibited by healthy individuals (Lehman 2004). CLBP subjects have been reported to engage in less general activity compared to healthy control subjects, for example demonstrating reduced step frequency, increased time lying and reduced time spent in standing during the day (Spenkelink et al. 2002). Additionally, pain reported during direction-specific functional activities are an integral aspect of the proposed MCI subgroups using the MDCS (O'Sullivan 2005) (Appendix II). It is therefore vital that robust kinematic measures of spinal movement patterns in both healthy and NSCLBP individuals can be identified during functional tasks. Greater understanding of functional movement strategies in NSCLBP could be of benefit for improving postural and functional re-education of movement, to prevent or reduce CLBP occurrence and identify maladaptive movement and motor control patterns in symptomatic individuals. Despite being proposed to be such an important factor in NSCLBP research, and an integral aspect of rehabilitation approaches, it is surprising there is such a paucity of literature into functional activity in these patient populations.

Bible et al. (2010) evaluated available ROM in the lumbar spine in a healthy cohort of 60 subjects. ROM in the lumbar spine was recorded using an electrogoniometer and torsiometer in 3 planes of movement (frontal, sagittal and transverse) during 15 simulated activities of daily living (ADLs) including: walking, ascending and descending stairs and picking up an object from the floor. It was concluded that healthy subjects only use a small percentage (3-49%) of available ROM to complete functional tasks. It could therefore be hypothesised that pain-free individuals utilise highly efficient movement strategies, with minimal range required from the spine, despite a greater ROM being available. Additionally, ascending and descending stairs utilised greater lumbar flexion during ascend compared to descend (11 vs. 8 degrees, $p<0.0001$). It may also be that the range of activities evaluated was insufficiently challenging to ROM thus explaining the limited range observed. Recurrent LBP was not specified as exclusion criteria, thus it is possible that some subjects (who had previously had LBP) may have underlying adaptive changes and subsequent restricted spinal ROM as demonstrated in previous work (Burton et al. 1989). Consistently with previous literature (Bible et al. 2008; Burton et al. 1989; Dvorak et al. 1995) age was identified to be a significant predictor for reduced active flexion and extension ($p=0.001$), lateral side flexion ($p=0.003$) and spinal rotation ($p<0.0001$) ROM.

Trunk movement during sit-to-stand, box lift and flexion in standing activities was evaluated in a sub-acute LBP cohort (n=12) in comparison with a healthy cohort (n=12) (Svendsen et al. 2013). No significant differences were observed in overall trunk angle (measured using a Qualysis™ motion analysis system) between groups. This may be due to trunk angle being considered as a single entity with markers placed on the acromion L5 and PSIS' alone, thus spinal curvature was not a factor considered within this study. Additionally, no subclassification approach to LBP was taken with the

sub-acute LBP group considered as a single, potentially heterogeneous group, thus homogeneous subgroups may have been concealed.

Silfies et al (2009a) investigated the kinematics of the lumbar spine in relation to the pelvis during a bilateral forward reaching task, comparing an healthy control group with a mechanical LBP (MLBP) group, all of whom had radiological evidence (reported via MRI) of moderate to severe degenerative disc disease (DDD). A 3Space Fastrak® system, with sensors placed on the femur, S2 and L1, determined the angular displacement of the lumbar spine in relation to the pelvis, whilst reaching for a target set at 50% of the individual's maximal functional reach, repeated with and without a 4.5kg load. The MLBP group was found to adopt a pelvis-dominated movement strategy ('pelvis-lumbar-pelvis') where the pelvis led in position and velocity in relation to the lumbar spine through most of the forward reach task. Conversely, the control group was found to adopt an alternative 'lumbar-synchronised-lumbar' motion to complete the forward reaching task, whereby the first 5% of movement occurred in the pelvis followed by an increase in lumbar velocity to move in synchrony with the pelvis through the remainder of the movement. The MLBP group were found to demonstrate significantly greater variability in return from full forward reaching, as well more variable co-ordination patterns overall as has been previously observed in static postures in NSCLBP previously (Bell 2008). These results may be further indicative of the reduction in proprioceptive acuity in the MLBP group as has been previously proposed (Brumagne et al. 2000). However, this increased variability in movement conflicts with previous findings of reduced postural strategy variability in the presence of pain (Moseley and Hodges 2006). Additionally the variable coordination patterns observed in the MLBP group further highlights that subgroups with distinct movement characteristics are concealed within this larger heterogeneous MLBP group. All MLBP subjects in this study had MRI evidence of moderate to severe degenerative changes in the spine, thus indicating a degree of structural change. Although these structural changes may have had no influence on functional ROM this may be a factor for consideration. A subclassification approach could be applied in future work to further explore these variable coordination strategies. The authors suggest reduced trunk extensor endurance to be a potential explanation for the alteration in the movement patterns adopted in the MLBP group, however EMG recordings of trunk muscle activity would be required to validate this hypothesis. It could be suggested these altered co-ordination strategies, in comparison to a healthy cohort, are less adaptable and hence encourage abnormal spinal loading to preclude on-going pain provocation in this population.

Movements integrating flexion and rotation of the spine are often reported as a trigger for pain onset in acute LBP, thus it has been suggested that evaluation of combined movements may be of greater diagnostic value in LBP populations (Allison and Fukushima 2003). Allison and Fukushima (2003) investigated the effect of ROM on spinal joint position sense in 23 healthy subjects and found no

differences in accuracy or precision in repositioning error across 10 repeated trials during a flexion-rotation task. Although these results were obtained via only 2 electromagnetic sensors placed at L5/S1 and a reference sensor at C7 and therefore the regional differences within the spine are unable to be established, these findings provide strong baseline support for good movement replicability in healthy individuals during these movements. As flexion-rotation is a key functional movement often reported as pain provocative in NSCLBP, it would be of value to explore whether these findings may or may not be replicated in flexion-rotation movements, or activities incorporating these movements, in a NSCLBP population.

Bending to pick up an object from the floor is another activity of daily living which may be impaired in the presence of chronic pain, however little literature exists profiling spinal kinematics of the activity in healthy individuals and how these biomechanical strategies may be altered in LBP populations (Shum et al. 2007a). Shum et al. (2007a) evaluated lumbar kinematics of 60 sub-acute LBP (with and without a positive SLR sign) and 20 healthy subjects during a sitting pick up object task. In unsupported sitting, subjects were asked to bend to pick up a light object (0.5 kg), at a self-selected comfortable speed, placed laterally and anteriorly to the heel (each side of the body). Total lumbar and hip motion was recorded using a 3Space Fastrak® electromagnetic device. It was observed that healthy individuals utilize flexion and side flexion of the trunk in order to pick up an object placed ipsilaterally, however in subjects with LBP (especially those demonstrating a positive SLR sign), lumbar spine flexion was significantly reduced compared to healthy individuals ($p<0.05$). The groups were not purposefully matched, although the authors suggest that similarities between groups are apparent, thus it is difficult to ascertain whether other determinants such as gender or age may have been a biomechanically influential factor within this cohort. The findings suggest that LBP subjects adopt different strategies to achieve the task by limiting trunk and hip movement. These initial findings suggest that bending to retrieve items tasks are important for evaluation, however it could be argued that retrieving tasks conducted in standing rather than sitting may be more of a functionally representative task.

Similarly the authors replicated these findings during a sitting to standing to sitting activities (Shum et al. 2005a), with significant limitations observed with regard to peak lumbar flexion in the LBP individuals compared to the healthy subjects. No significant differences were observed between the LBP individuals with and without a positive SLR sign. Interestingly, the authors also observed velocity of lumbar movement to be reduced overall in the LBP group indicating that it took these individuals longer to move from standing to sitting and to reach peak lumbar flexion. Subjects reported pain duration of >7 days and <12 weeks, so further work would be required to establish whether these altered movement strategies are apparent in the presence of chronic pain. Additionally

the cohort used was male only with a narrow age range, thus may only represent a small demographic of the overall sub-acute LBP population.

Mitchell et al (2008) used 3Space Fastrak® to record regional lumbar spine posture in a general female student nursing cohort (n=170) during functional tasks including: picking up a pen from the floor; lifting a box from the floor; transferring a pillow from left to right on a table; transferring a box from left to right on a table; and squatting. Distinct differences between the lower lumbar (LLx) and upper lumbar (ULx) peak angles were observed for the pick up pen, pick up box, pillow transfer and box transfer tasks, however no differences were observed for the squatting tasks. Significant differences were also observed during the pick up pen, lifting a box from the floor and squatting with regard to how far ULx and LLx peak angles deviated from the usual standing position, with a significant increase in movement in the LLx, however only squatting was observed to be significant after adjustments were applied for BMI. These findings again suggest that differences in movement patterns are apparent when the lumbar spine is subdivided into an upper and lower region during usual functional activities, as well as previously established in spinal postures and ROM. The specific occupation of this cohort (nursing) reduces the extent to which these findings are applicable to the wider population. It may be due to the nature of their work that specific repetitive activity (e.g. forward bending) may predispose individuals to similar movement and motor control adaptations in the spine. The degree of LBP was established through lifetime LBP severity scores (VAS), LBP duration in the previous 12 months, activity limitation, treatment or medication required for LBP in the previous 12 months and current ODQ scores. Subjects were subsequently categorised as having significant, mild or no pain. When degree of LBP was accounted for, correlations between lower and upper lumbar spinal regions were found to be similar in all tasks, however this approach to quantifying pain may not give a clear reflection of current pain levels thus the data is difficult to interpret in the context of the results. Due to occupational postures, which are required, or previous manual handling training, it could be argued that these individuals may have been trained in certain postural movement behaviours, therefore exploring these tasks in other populations is warranted.
An aspect of functional activity for which further research is warranted is the influence of lifting weighted items. Although trunk muscle activity and spinal loads are likely to be influenced by the orientation and height of external forces being lifted, spinal kinematics have been previously demonstrated to remain unchanged during tasks involving lifting external weighted objects at differing heights in healthy individuals (n=12) (El Ouaaid et al. 2014). It would be of interest in future research to not only evaluate picking up an item from the floor but also lifting a weighted item at trunk height in subclassified groups of NSCLBP individuals, to establish whether differences in spinal kinematics, as well as trunk muscle activity exist during this activity.

2.5.1.4 Summary of Spinal Kinematics

It is clear that there is a lack of current research conducted into spinal movement behaviour during in functional activities, especially with regard to understanding movement behaviours in LBP populations. Work by Shum et al (2005a, b, 2007a, 2010) has consistently demonstrated that the lumbar spine motion is significantly restricted in the performance of a number of functional tasks in LBP populations, however the mechanisms for these strategies are not fully understood and further work is required to more fully understand how spinal kinematics are influenced in different NSCLBP presentations.

The majority of current literature regarding spinal movement patterns during functional activities is inconclusive, with some studies reporting pain to influence ROM and other work questioning this phenomenon. As discussed previously, the omission of a classification strategy is a major limitation to the studies presented due to the heterogeneity of NSCLBP. Additionally, little work has currently been undertaken evaluating the thoracic spine. Multiple studies report between group differences in the upper lumbar region but few explore the spinal regions beyond this. It may be that the thoracic spine is also a key area for investigation in differentiating between symptomatic and healthy control subjects. Future studies should also investigate ROM throughout the whole spine, including the thoracic spinal region during functional activity to address this research question.

2.5.2 Muscle Activity

2.5.2.1 Muscle activity and Pain

It has been hypothesised that motor control impairments may be secondary adaptations following exposure to pain, which in turn may brace the spine as a short term adaptive strategy thus leading to long-term adverse affects (Hodges and Moseley 2003; Hodges and Richardson 1996; Mehta et al. 2010; Silfies et al. 2009b; van Dieën et al. 2003). Further to this hypothesis, Lund et al. (1991) suggested that motor control strategies may be employed in the presence of pain to limit movement of a painful area. It has been suggested that, in the presence of pain, agonist muscle activity decreases whilst antagonist activity increases to potentially limit velocity, force and overall ROM (Svensson et al. 1996). A reduction in the mass of trunk extensor muscles following an acute onset of LBP has also been suggested as potential precursor to CLBP (Hides et al. 1996), however other studies have conversely reported that a lack of an association exists between LBP and muscle (LM) density (Kalichman et al. 2010). Additionally changes in muscle fibre characteristics have also been shown to occur in CLBP patients, with Mannion et al (1997) identifying paraspinal muscle samples from CLBP

patients to have a higher volume of type 2 (fast twitch) fibres compared to healthy controls, which demonstrated a higher percentage of type 1 (slow twitch) muscle fibres. These findings suggest that the threshold to muscle fatigue in this symptomatic group may be much lower (Mannion et al. 1997). Hence it is clear that accurate measurement and evaluation of muscle activity is paramount to identifying potential characteristics of motor control dysfunction in CLBP. The following section outlines the current research evaluating the effect of pain on muscle activity of the trunk.

To enable direct comparisons to be drawn in a healthy subject cohort, experimentally induced pain has been utilized as a methodological approach with which to investigate alterations in trunk muscle activity responses. Hodges et al (2003b) evaluated the effect of pain on trunk muscle activity during rapid upper limb movements, following an intramuscular hyper-saline injection into the longissimus muscle at the level of L4. Transversus abdominis (TrA) onset was found to be consistently delayed in the presence of experimentally induced pain with reduced mean EMG amplitude ($p<0.02$), peak ($p=0.02$) and troughs ($p=0.02$) and displayed delayed onset in comparison to deltoid onset in a single arm movement task and a repeated upper limb movement task. This has been concurrently demonstrated in patients with a history of recurrent LBP but who, at the time of investigation, were in remission of pain (Hodges and Richardson 1999). These findings are supported by previous studies (Hodges and Richardson 1998; Hodges and Richardson 1996) however, this phenomenon has been refuted, with evidence to suggest that a proportion of healthy individuals (20%) do not display feed-forward activation of Transversus Abdominis/internal oblique (TrA/IO) prior to rapid upper limb movement (Marshall and Murphy 2003). In addition Mannion et al. (2012) identified no significant correlations in TrA feed-forward activation in CLBP individuals pre- and post- a 9 week spinal stability intervention. Similarly to Marshall and Murphy's (2003) work, Hodges et al (2003b) used unilateral rapid upper limb movements to evaluate trunk muscle activity onset, however Marshall and Murphy's (2003) cohort performed the task in response to verbal command rather than a light stimulus (Hodges et al. 2003b). Marshall and Murphy (2003) observed no significant differences between healthy and NSCLBP groups when the protocol was repeated at slower speeds thus it may be difficult to detect differences in muscle activation between these groups during usual functional activities. All other muscles tested (TrA, EO, IO, superficial and deep LM) using fine-wire EMG produced highly variable responses to pain demonstrating no consistent activation patterns. This study is difficult to extrapolate conclusions from as only 7 participants were investigated, with one of the participants demonstrating no change in TA delay 1-hour post hyper-saline injection. However, this finding alone is of interest as it infers that even with such a short exposure to pain, longer-term adaptations are evident 1 hour following pain cessation. Further studies would be required to validate or negate this hypothesis to explore whether this phenomenon would be present in a larger cohort. The study suggests that pain may be the underlying primary cause for motor control impairments with regard to CLBP. However the findings are only valid for acute short-term experimental pain in

healthy individuals. The effect of long-term exposure to pain is also unclear from this study as chronic pain may pre-determine the development of motor control impairment patterns.

Marshall and Murphy (2010) repeated a similar protocol in a CLBP population (n=80), to evaluate TrA/IO (recorded using sEMG) during unilateral rapid shoulder movements. Three-quarters of subjects presented with reduced feed-forward activation of TrA/IO, however, surprisingly, these individuals reported lower levels of disability (ODQ) (23.2+/-6.9% vs. 31.0+/-9.2%, mean difference 7.8%, 95% CI 3.9 to 11.6%, $p<0.001$) compared to the individuals who did not display reduced feed-forward activation. This is an interesting finding as it questions the importance of TrA activation as an indicator for LBP as it appears that not all CLBP patients exhibit delayed feed-forward activation of TrA/IO. Additionally, TrA/IO has been previously identified to have a limited contributory role to the stability of the spine (Kavcic et al. 2004). Thus it may be more clinically relevant to consider the interplay of multiple muscles in establishing possible links with pain chronicity (Cholewicki and McGill 1996; Cholewicki and VanVliet 2002; Kavcic et al. 2004). The use of surface, rather than fine-wire, EMG to determine TrA/IO activity may also be a contributory factor to the conflicting findings.

Another interesting finding of Marshall and Murphy's (2010) study was a significant relationship between latency times of TrA/IO and self-rated pain scores (VAS). Regression analysis showed 17% variance in pain scores for the entire population were explained by latency times measured which was further strengthened when the population was subdivided into individuals who presented with (n=20), and without (n=60) feed-forward TrA/IO activation (Marshall and Murphy 2010). This demonstrates a clear link between anticipatory activation of deep abdominal musculature and an increase in self reported pain in CLBP.

Mehta et al. (2010) similarly demonstrated a lack of a feed-forward response during voluntary extremity movements in both a control (n=30) and NSCLBP cohort (n=30) with onset latencies not only in TrA/IO, but also EO, RA and sLM muscles, observed to be more variable in both cohorts. This may arguably be due to an increased average age of participants (approx. 11 years) and methodological differences regarding the use of sEMG compared to Hodges et al. (2003b) and Hodges and Richardson (1999). Interestingly, Mehta et al. (2010) found the NSCLBP group to display significantly delayed muscle onset latency ($p<0.01$), and shorter co-contraction durations ($p<0.01$). Thus it may be that feed-forward activation alone is insufficiently able to discriminate between NSCLBP and healthy individuals and that other parameters of muscle activity are required to establish mechanisms underlying inefficient postural strategies in the presence of NSCLBP.

These studies consider static postures alone, in conjunction with perturbations created by rapid or voluntary limb movements, therefore it is difficult to compare results directly with natural functional movement. In support of these observations, feed-forward anticipatory activation of TrA and alterations in this response in LBP subjects have also been replicated in relation to lower limb movement (Hodges and Richardson 1997; Hodges and Richardson 1998), however further research needs to incorporate usual functional activities to conclude whether these phenomena occur during everyday tasks.

Pinto et al. (2011) investigated TrA activation, measured as a change in thickness using ultrasound imaging, during voluntary muscle contraction (abdominal hollowing). This was performed with the lumbar spine in either a neutral or flexed posture in supine lying in 60 participants (30 LBP, 30 healthy). Lumbar posture was found to have an impact on TrA similarly in both groups. Posture was shown to be a significant differentiator of TrA activation ($p<0.001$) with neutral lumbar posture observed to improve TrA activation in both the LBP and healthy groups (mean difference, 7.5%; 95% CI 3.8%-11.3%). No significant between group differences were identified. These results show that posture of the lumbar spine does alter the ability to activate TrA and change thickness during neutral lumbar spine posture, suggesting 'optimal' neutral spinal postures to be more desirable to normalise motor control strategies. Interestingly, this ability was unaltered in between the LBP and healthy groups, suggesting that this can occur in the presence of pain. If posture can have a significant effect on muscle recruitment, as demonstrated in this study, then postural re-education towards neutral spine control may be paramount to the long-term cessation of LBP. However voluntary muscle contraction in this study was performed in supine lying, thus the muscles are able to activate with the effect of gravity eliminated. Whether the differences observed would be replicable during upright postures, or even more dynamic activity such as stepping or bending, remains to be established.
It appears that the TrA and IO muscles may have a role in anticipatory activation prior to limb movement in healthy subjects, with delayed activation observed in CLBP subjects observed in a proportion of the literature. However this is disputed to an extent, therefore consideration of global trunk musculature activation, incorporating evaluation of other muscles (e.g. EO, LT, LM) is required to evaluate differences between NSCLBP and healthy individuals.

Silfies et al. (2009b) used sEMG to evaluate feed-forward activation in a mechanical LBP (MLBP) ($n=43$) and a healthy control group ($n=39$) in 10 trunk muscles (bilateral TrA/IO, lumbar ES, EO, superficial LM (sLM) and rectus abdominis (RA)) during rapid shoulder flexion. Statistically significant differences were observed between the groups with regard to muscle activation timings ($p<0.01$) and the number of muscles demonstrating feed-forward activation ($p=0.02$). In the control group significantly earlier feed-forward activation was observed in the contralateral external obliques (EO) ($p=0.006$), sLM ($p=0.008$) and lumbar ES ($p=0.011$) and ipsilateral TrA/IO ($p=0.003$)

musculature compared with the MLBP group. A novel aspect of this research was that further analysis was conducted on the MLBP group through subgrouping individuals into those presenting with 'instability' (n=25) and a 'non-instability' group (n=18), with instability defined as demonstrating moderate degenerative disc disease changes on MRI and positive low pressure discography at one or more levels in the lumbar spine. Interestingly significant between group differences were observed with regard to muscle activation with the non-instability group demonstrating similar results to the control group. These findings highlight the need for CLBP to be sub-grouped as muscle activity appears to differ within sub-populations of this disorder. The study also emphasises the differences in muscle activity between healthy individuals and LBP subjects with regard to the EO, LM and ES musculature, thus as well as TrA/IO, these are also key muscles for consideration in future CLBP research. Both TrA and LM are recognised to be key muscles providing stability in the lumbar spine. An in vivo porcine study revealed that spinal stiffness may be increased in the presence of increased TrA stimulation (Hodges et al. 2003a), however it has been proposed that the LM may contribute the largest proportion of spinal 'stiffness' in the trunk during neutral postures (Wilke et al. 1995).

Hides et al (1994) found the ipsilateral cross-sectional area (CSA) of multifidus to be reduced (between-side difference 31 +/- 8%) as little as 24 hours after an acute onset of unilateral LBP. However, this significant difference was confined to one spinal level. Above and below this level, between side difference was found to be <6%. The authors therefore hypothesise that this finding may not be as a result of generalized disuse atrophy but spinal reflex inhibition which is proposed to occur when sensory stimuli prevent voluntary muscle activation to cause muscle atrophy and weakness (Hides et al. 1994). Although CSA of the LM does not demonstrate a direct relationship to motor control, the findings support Hides et al's (2001) observations that following a specific exercise intervention targeting multifidus, alongside TrA co-contraction (in combination with medical management and return to normal activities) a significantly lower LBP reoccurrence rate at 1 and 3 years (30% vs. 84%; 35% vs. 75% respectively) is observed (when compared to medical management and advice alone), indicating that LM activation dysfunction may play a key role in driving LBP chronicity. Interestingly, Hides et al (1994) found that the degree of asymmetry between the ipsilateral and contralateral side did not correlate with symptom severity to further demonstrate the poor correlation between structure, pain and disability in NSCLBP. The findings of Hides et al's (2001; 1994) studies provide evidence that activity of the deep spinal muscles is significantly reduced in currently symptomatic LBP sufferers as well as those currently who are currently asymptomatic but report recurrent pain.

More recently MacDonald et al (2009) found that muscle activation in the short fibres of LM were, in concordance with Hodges et al. (2003b) TrA findings, delayed in relation to the onset of deltoid muscle activation in a rapid arm movement task (p=0.022) in individuals with unilateral recurrent

LBP who were asymptomatic at the time of testing (n=15), compared to a healthy control group (n=19). Interestingly, in the healthy cohort the short fibres of LM were activated earlier than the long fibres, which was also consistently identified in the unaffected side in the LBP group but not the previously symptomatic side. This suggests there to be a difference in muscle activation patterns of the deep lumbar musculature, which could be proposed to be a mechanism for pain recurrence. However, due to the small sample size in both the recurrent back pain group and the control group, the extent to which these findings can be extrapolated is limited, due to the chance of attaining a type 2 error (false positive) (Field 2009). The findings do however further support the hypothesis that the muscle activity of the deep back muscles is impaired not only in patients with current back pain but also those who have had previous exposure to back pain. Whether these changes occur at a simple motor neurone level, or as a result of more global adaptive changes in motor planning, i.e. inaccurate spinal sensory information or altered strategies of the nervous system (Hodges 2001; Leinonen et al. 2003; Moseley and Hodges 2005) is to be ascertained.

Although a significant volume of work has been conducted on changes in muscle activation in the presence of pain, it is important to understand how muscle activation may be influenced during functional tasks to establish how clinical interventions could be used to target dysfunctional activation patterns.

2.5.2.2 Flexion-Relaxation Phenomenon

Studies have consistently shown that in full end range spinal flexion in standing inhibition of back musculature occurs in healthy individuals, known as the 'flexion-relaxation phenomenon' (FRP) (Andersson et al. 1996; Floyd and Silver 1955; Kaigle et al. 1998; Kippers and Parker 1984; Mathieu and Fortin 2000; Neblett et al. 2003; Schultz et al. 1985; Solomonow et al. 2003). The mechanism for this phenomenon is proposed to occur due to a transfer of the spinal load from active to passive structures (or other active structures) at the end of range (McGill and Kippers 1994), however this is not definitively understood (McGorry and Lin 2012). FRP may be to be due to stretch reflex inhibition, where a reflexive contraction is produced by the muscle spindle following passive longitudinal stretching (Floyd and Silver 1955; Kippers and Parker 1984) or, alternatively, passive spinal structures (i.e. lumbodorsal fascia, spinal ligaments, passive tension of ES) could provide sufficient control in order to achieve full flexion, eliminating the need for active muscular control at end range (Adams et al. 1980; McGill and Kippers 1994).

FRP has been shown to be consistently absent in individuals with NSCLBP (Ahern et al. 1988; Ahern et al. 1990; Shirado et al. 1995; Watson et al. 1997) where no period of electrical silence in the back musculature is observed at end range of spinal flexion. It appears that in symptomatic LBP individuals

these muscles remain activated at end range flexion, which could be proposed to be due to perceived spinal instability or fear of the patient, causing co-contraction of the extensor musculature.

Psychosocial factors have been suggested to influence the omission of this response in relation to pain (McGorry and Lin 2012). It may also be as a result of an increased muscle spasm response in response to localised pain, where the spinal musculature remains activated. These alterations in trunk muscle recruitment have been previously proposed as functional adaptations to pain in order to reduce sensitizing pain sensitive tissues through limiting ROM and enhancing spinal stability (van Dieën et al. 2003).

Sustained activity of ES at end-range of spinal flexion in CLBP subjects has been previously observed (Callaghan and Dunk 2002; Shirado et al. 1995) as well as in subjects where pain was replicated experimentally (Zedka et al. 1999). Furthermore, research by Kaigle et al. (1998) has suggested that sustained activity of lumbar ES at end range spinal flexion can limit intervertebral motion in CLBP individuals compared with healthy subjects.

Dankaerts et al. (2006a) observed a significant reduction in Flexion relaxation ratio in the sLM ($p<0.001$) and ICLT ($p<0.001$) muscles in the pooled NSCLBP group compared to the healthy group when moving from usual to slumped sitting postures, however no significant differences were observed between the AEP and FP groups for either muscle group (sLM or ICLT). These findings replicate previous literature in NSCLBP subjects observed in standing (Ahern et al. 1988; Ahern et al. 1990; Shirado et al. 1995; Watson et al. 1997) to demonstrate that there appears to be no flexion relaxation response in NSCLBP subjects in sitting. Additionally the subclassification using the MDCS does not appear to be a discriminatory factor for FRP with both FP and AEP patients exhibiting an inability to 'switch-off' the back musculature during end range flexion in sitting.

Interestingly, Astfalck et al. (2010b) was unable to replicate these findings in an adolescent cohort, as FRP was observed in the iliocostalis ($p=0.042$) and thoracic erector spinae ($p=0.043$) musculature in the pooled NSCLBP group but not in the control subjects. The AEP group similarly displayed an FRP in the iliocostalis muscle ($p=0.038$). Additionally increased muscle activity in the multifidus ($p=0.010$) in the healthy control group further clouds the picture. Although these adolescent individuals appear to display clear similarities with regard to spinal kinematics in the MDCS, muscle activity and FRP appear to demonstrate very little resemblance to the findings of the adult population. One could postulate as to the reasons for this, one reason may be that older adults may exhibit greater levels of pain and disability where there is an absence of the FRP in the back musculature (Astfalck et al. 2010b; Dankaerts et al. 2006a).

FRP phenomenon may be also apparent during other activities. Arendt-Nielsen et al. (1996) noted ES activity silences to be significantly reduced in LBP patients during the swing phase of gait, as well as healthy participants exposed to experimentally induced pain. These findings suggest that, to some extent, ES may serve to 'splint' the spine during pain (Hodges and Moseley 2003) and thus ES may be a muscle for consideration when planning NSCLBP research.

2.5.2.3 The Effect of Spinal Posture on Trunk Muscle Activity

Muscle activity has been shown to have a direct link with sagittal spinal sitting posture in a study evaluating fine-wire EMG of the deep and superficial LM, iliocostalis, longissimus thoracis, and TrA in 14 healthy male subjects (Claus et al. 2009a). Three spinal postures were evaluated in sitting: flat (flattened lumbar and thoracic); long lordosis (lordotic lumbar and thoracic); and short lordosis (thoracic kyphosis, lumbar lordosis). Deep and superficial LM activity was found to increase incrementally between postures (flat, long lordosis, short lordosis respectively) ($p<0.05$) with IO observed to be most active during short lordosis sitting posture. Overall, the least muscle activity was observed in the flattened posture type. This is the proposed posture type of the FP group, potentially adopting a more 'slumped' sitting posture, thus it may be hypothesized that FP will demonstrate the least overall activity compared with the AEP group who, may better reflect the long lordosis posture. The adoption of a 'trunk stiffening' strategy during upright standing has been reported in LBP populations. Compared to healthy individuals, patients with LBP have been demonstrated to display overall reductions in trunk torques, with associated increased activity in the trunk musculature in response to sudden perturbation during standing (Jones et al. 2012). This suggests that in order to maintain stability LBP subjects increase overall muscle activity around the trunk to stabilise, perhaps due to an inability to fine tune a balanced spinal motor control response, i.e. an inability, or reluctance, to use spinal and/or hip movement as a stabilising strategy, or due to fear of pain (i.e. maladaptive avoidant strategies).

O'Sullivan et al (2002b) evaluated the effect of both standing and sitting postures on trunk muscle activity in healthy subjects (n=20). A reduction in IO, sLM and thoracic erector spinae (TES) activation during sway standing and slump sitting, in comparison to their relative erect postures was noted. This increase in activity in the IO, sLM and TES muscles during more 'passive' postures may suggest that FP patients display similar patterns of activation during sitting as they habitually adopt more end range flexion, arguably 'passive' sitting postures. Later research (O'Sullivan et al. 2006b) observed differences in trunk muscle activation in sitting postures in another small (n=22) healthy cohort. sEMG of sLM, iliocostalis lumborum pars thoracis (ILPT), TES, EO, IO and rectus abdominis (RA) muscles were compared during upright 'thoracic', upright 'lumbo-pelvic' and slump sitting.

sLM and IO activation levels were noted to be significantly reduced in upright thoracic sitting. Conversely an increase in TES and EO activity was noted during this sitting posture. Interestingly, no significant differences were found in this study between sLM activity in upright sitting and slump sitting, in contrast to significant differences in sLM activation observed between more 'passive' and 'active' postures previously (O'Sullivan et al. 2002a). In healthy individuals there appears to be an ability to dissociate regional muscle activity in response to regional postural change. How this muscle activity pattern alters in symptomatic individuals is therefore an area for further investigation, especially regarding regionally postural adaptation and its effect on regional muscular activity. No significant changes were observed in RA which may indicate that the role of RA may not change in different static postures (O'Sullivan et al. 2006b). Muscle activation in this study was calculated against maximal voluntary contraction (MVC) values, which have been found to be inappropriate in evaluating sEMG in LBP (Dankaerts et al. 2004). However, the significant differences in muscle activation between the sitting postures suggest specificity of postural retraining to be important for postural re-education in NSCLBP.

The combined findings of these studies provides support for upright lumbo-pelvic sitting as an 'optimal' spinal posture as it involves no end range positions. Therefore local spinal stabilisers such as IO and sLM, which are more resistant to fatigue, are preferentially activated (O'Sullivan et al. 2006b). Hence, by recruiting local stabilising musculature, vertebral load sharing may be optimised and consequently stress on sensitised passive spinal structures reduced. These studies demonstrate a clear link between posture and muscle activity. The MDCS MCI subgroups (FP, AEP) are proposed to demonstrate significant directional differences in sagittal spinal posture. Thus it is clearly important to ensure future work considers both spinal kinematics and muscle activity to establish how whether these postural differences are maintained throughout functional tasks and establish how muscle activity is resultantly influenced in these MCI NSCLBP subgroups. The following section will establish the current evidence base evaluating trunk muscle activity in healthy subjects and LBP subjects during functional activities.

2.5.2.4 Muscle Activity during Functional Activities

To date, little work has been conducted to evaluate trunk muscle activity variation during functional tasks between NSCLBP subjects and healthy controls.

Muscle activity during sit-to-stand, box lift and flexion in standing activities was evaluated in a sub-acute LBP cohort (n=12) in comparison with a healthy cohort (n=12) (Svendsen et al. 2013). Overall muscle activity of the bilateral EO and ES musculature were recorded. Left EO activity was found to

be significantly lower in the LBP group compared to the healthy control subjects in contrast to previous studies where no significant differences in muscle activity of the EO were observed (Ferreira et al. 2004). However, interestingly this was not observed in the right sided musculature despite trunk flexion considered a symmetrical task, thus it may be important for the left and right musculature to be analysed independently in future studies of dynamic activity, despite symmetry of the task. Interestingly, left EO was found to be positively correlated ($p \leq 0.05$) with subjectively reported catastrophising scores (analysed using the Coping Strategy Questionnaire) to further emphasise the link between catastrophising and muscle activity, which has been previously observed in CLBP (van der Hulst et al. 2010b). Although these findings relate to sub-acute pain, they further support the presence of muscle 'guarding' responses observed previously in CLBP groups (van der Hulst et al. 2010a).

Kiesel et al. (2012) evaluated LM muscle activation in 17 healthy adults exposed to experimentally induced pain (pain induction protocol as per Hodges et al (2003)). Individuals performed repeated shoulder flexion and extension, and staggered-stance weight shifting tasks in standing. Intramuscular EMG of LM was recorded at baseline, during induced pain and once pain resolved. Varied results were obtained. Increased activity (magnitude) in the induced pain condition was observed compared to baseline recordings during the shoulder extension task ($p=0.04$), however reduced activity was observed during the weight shift task during the pain induced phase ($p=0.02$) and recovery phase ($p=0.01$). Additionally, backward weight shift demonstrated reduced activity during the recovery phase compared to baseline ($p=0.03$). It may be that LM is less responsive to pain compared to other musculature involved in spinal stability. Also, experimentally induced pain is acute thus maladaptive postural behaviours previously observed in chronic presentations may not be apparent. Tasks may be insufficiently challenging for trunk musculature in order to accurately discriminate between differences in the pain and no pain conditions.

Muscle activation and muscle thickness have also been evaluated during more functional activity in the TrA, IO and EO muscles. Ferreira et al. (2004) evaluated muscle activity using fine wire EMG and concurrent ultrasound in a LBP ($n=10$) and healthy ($n=10$) cohort. Following isometric knee flexion and extension low load tasks, performed with the patient supine on a plinth and the lower limbs suspended, it was established that LBP demonstrated a smaller increase in TrA thickness and less TrA muscle activity during the task compared with the control group. This further supports previous research findings (Hodges et al. 2003b; Hodges and Richardson 1998; Hodges and Richardson 1996). No differences were observed however between the LBP and healthy control group in the IO and EO muscles with regard to muscle thickness or muscle activity. It may be that the obliques are less affected in the presence of pain. This study, although arguably challenging the trunk

more dynamically than shoulder movement, is not a functional activity, thus replicating usual functional activity is a key priority for future work.

2.5.2.5 Summary of Muscle Activity

These studies demonstrate a clear link between muscle activity and motor control dysfunction in NSCLBP. This reduction in 'fine tuning' at the lumbar spine has been proposed as a primary mechanism for recurrence in low back pain (Kaigle et al. 1995). It could therefore be hypothesized that in chronic pain populations (NSCLBP) these motor control impairments have become so well established that the patient becomes unable to move out of the movement / motor control pattern and hence continually drive into pain as a secondary compensation to an initial event.

Understandably previous research on trunk muscle activity has focussed largely on highly standardised movements and procedures however these are often not reflective of the patients' usual muscle activity recruitment. However very little research exists into muscle activity during natural functional tasks thus this is a crucial area for future work to better understand how spinal posture and muscle activity are manifested in subgroups of NSCLBP populations.

2.6 Evaluation of Spinal Biomechanics: Methodological Approaches

2.6.1 Spinal Kinematics

Spinal kinematics are fundamental to understanding spinal movement to enable patients to be categorized based on their ability to undertake different functional tasks (Lehman 2004). Currently, there is a paucity of research comprehensively investigating kinematics of the trunk, which has been attributed to the cost, preparation time and customized software required (Lehman 2004).

Many different methodologies have been proposed to investigate spinal movement both statically and dynamically. These can be broadly defined in two categories: *indirect* whereby the skin surface is used to estimate the movement occurring in the spinal vertebrae; or *direct* whereby the movement of the spinal vertebrae is explored, usually by radiographic methods or the insertion of pins directly into the spinous processes (Bryant et al., 1989). Direct methods include: inclinometers including electric inclinometers such as the spinal mouse®; flexicurve; photogrammetry; accelerometers; goniometers; electromagnetic devices; optoelectronic devices; and Zebris®, a system utilising ultrasound

transmitters. Indirect methods include: radiographic analysis such as x-rays, magnetic resonance imaging (MRI); and fluoroscopy. Although many of these methods have established reliability, most are limited to postural and static measurements. The ability to measure throughout ROM and during dynamic activity is required to comprehensively understand spinal kinematics in NSCLBP.

Existing research into lumbar spinal kinematics of NSCLBP subclassified according to the MDCS has been primarily conducted using a 3Space Fastrak® system, an electromagnetic device previously shown to be a reliable and valid approach for lumbar spine measurement (reported accuracy 0.2°) (Pearcy and Hindle 1989). Dankaerts et al. (2006c) used 3Space Fastrak® to detect differences in sacral tilt, lower lumbar and upper lumbar spinal postures between AEP, FP and healthy groups where the tool was demonstrated to be sensitive enough to detect between group differences. Advantages of the approach are that both lower and upper lumbar angles can be recorded (Dankaerts et al. 2006c) and changes in spinal curvature can be recorded continuously throughout dynamic movement, however the approach is not able to identify differences in multiple spinal regions (e.g. in the thoracic and lumbar spine simultaneously).

Other research evaluating MDCS MCI subgroups has collected data using a novel continuous Posture Measurement Device (BodyGuard™) developed by O'Sullivan et al. (2011). The device, which utilizes a 'strain gauge', is a non-invasive portable posture monitor to evaluate static postures beyond the laboratory environment. Additionally it has the advantage of providing postural feedback. The device has been shown to exhibit excellent between-day and inter-tester reliability (O'Sullivan et al. 2011) and demonstrable validity when compared to a surface-marker based system (CODA™) (O'Sullivan et al. 2012b) and videofluoroscopy (O'Sullivan et al. 2012b), suggesting the device to accurately reflect the motion of the underlying vertebrae. BodyGuard™ has been utilised by Van Hoof et al. (2012) to identify differences in lower lumbar spinal angle in cyclists with FP impairments and healthy cyclists, over 2 hour time period, as well as in studies evaluating ergonomics for sitting postures in FP (O'Keeffe et al. 2013) and AEP populations (Curran et al. 2014). However the approach is limited in that it is only able to evaluate spinal posture in a single region (e.g. L3 to S2) and thus is unsuitable for evaluation of the total spine and unable to differentiate between spinal regions concurrently.

As discussed previously (section 2.5.1.2) regional spinal differences in the upper and lower lumbar spine have been shown (Mitchell et al. 2008), thus techniques which are able to differentiate between different spinal sub-regions as well as recording dynamic spinal movement in both the thoracic and lumbar spine are required. For this purpose optoelectronic devices are considered the 'gold standard' for direct spinal measurement due to the ability to capture real-time spinal movement to a high degree

of accuracy. These systems are non-invasive and are advantageous as they should not generally influence movement patterns and motor control strategies (Cutti et al. 2005)

It has however been purported that external measurement of the spine (e.g. inclinometry, goniometry, analysis using surface markers) may not fully reflect underlying intervertebral movement due to the potential for skin movement when moving through dynamic tasks particularly when distances between skin marks are measured (Portek et al. 1983). However, it has been proposed that skin surface marker positions can be an "index of back movement" to provide an overview of global patterns of spinal movement (Ng et al. 2001). Additionally, optoelectronic devices have been reported to have high levels of reliability with reported errors of approximately ± 2° during anatomical movements (Pearcy et al. 1987) and lumbar spinal movement patterns recorded using optoelectronic devices have been shown to demonstrate a high degree of agreement with radiographical techniques (Pearcy et al. 1984, 1985), to support this approach as a reliable tool for assessing spinal motion.

An issue with spinal measurement using optoelectronic devices is determining how representative spinal marker placement is of the underlying spinous processes of the vertebrae as soft tissue artefact is aspect for consideration which can influence the reliability of the results obtained (Cutti et al. 2005) as well as human error with regard to spinal palpation and marker placement. Another potential source of error is close proximity of markers causing 'cross-talk' and thus affecting kinematic results. This can be overcome with the use of good robust marker sets for the spine, which have sufficient markers to report the kinematics of the spinal regions of interest. A systematic review to evaluate current spinal marker set usage and established reliability is outlined in Chapter 4.

Despite these limitations optoelectronic devices are a flexible approach to spinal kinematic evaluation as marker sets can be developed to evaluate any region and plane of movement, data can be collected during dynamic functional movements and kinematics of other regions can be calculated (e.g. knee, pelvis) to provide comprehensive biomechanical information regarding global movement strategies. Although optoelectronic devices are often considered to be a complex and time-consuming approach to spinal measurement, and thus unsuitable for routine clinical application (Lee 2002), they provide a good option for in-depth biomechanical analysis in a research environment.

2.6.2 Electromyography

The ability to obtain accurate muscle activity recordings is crucial in order to develop biomechanical understanding of spinal movement and motor control adaptations in the trunk in both healthy and NSCLBP populations. Electromyography (EMG) is an experimental technique widely used to record

and analyse the electrical activity produced by skeletal muscle. These myoelectric signals are the summation of the discharges of all the motor units within the electrode range (Basmajian and De Luca 1985). In the study of kinematics EMG can be considered to be a measure of 'neuromuscular activation' of muscles during either static and more dynamic functional tasks (Konrad 2005).

Two types of EMG techniques are in widespread use: sEMG, whereby electrodes are placed directly onto the skins surface; and intramuscular fine-wire EMG, an invasive electrode procedure which involves needle insertion into the abdominal wall under ultrasound guidance (Marshall and Murphy 2003). This approach is often used to establish muscle activation levels in deep musculature, however is invasive and has practical implications and constraints. Due to the non-invasive nature, and the ease of application, of surface electrode application, sEMG is the approach most commonly used in kinematic research (Dankaerts et al. 2004; Konrad 2005).

The use of sEMG has been extensive in the exploration of LBP, and comparative assessments of healthy individuals, as a means of describing alterations in trunk movements and postures (Dankaerts et al. 2006a; Jones et al. 2012; Larivière et al. 2002; Neblett et al. 2013; Oddsson and De Luca 2003). However there are many confounding variables potentially affecting sEMG including levels of subcutaneous fat which has been hypothesised to produce up to 81.2% of sEMG amplitude variance in paraspinal musculature (Hemingway et al. 1995). Levels of skin impedance, errors in electrode placement, environmental temperature, body temperature, 'cross-talk' from neighbouring musculature, and external noise (e.g. heart rate) can also significantly affect the sEMG recordings. Consideration of these factors is described in detail in section 6.7.2.

Reliability and reproducibility of sEMG is an important consideration to ensure muscle activity is accurately recorded. Larivière et al. (2002) evaluated between-day reliability of sEMG in 4 back muscles (bilaterally): LM (at L5), iliocostalis lumborum (at L3) and longissimus thoracis (at L1 and T10). Testing was conducted on 3 occasions, minimum 2 days apart, in a healthy control and CLBP group during a trunk extension task. Average recordings of bilateral LM and longissimus demonstrated the highest levels of between-day reliability (ICC 0.74-0.79). The approach of Larivière et al. (2002) using dynamometer feedback during trunk extension is standardised, however this is not reflective of muscle activity performed during usual functional tasks as the individual may choose to perform certain tasks using alternative movement strategies.

Danneels et al. (2001) investigated reliability of sEMG measurements in spinal musculature in 15 healthy subjects. Subjects were tested on 3 occasions a minimum of 1 week apart during 22 exercises categorised as either: stabilisation, balance, co-ordination and strength. Increased reliability was observed in LM compared to ICLT. Additionally, reliability was highest in activities involving higher

loads, such as strengthening activities. Intra-tester reliability was observed to be good in all activities (ICC>0.75) except balance (ICC=0.40 to 0.74) suggesting that during these activities mean amplitude EMG is reliable when performed by the same tester. However inter-operator reliability (3 testers, interval of 1 week) of sEMG for measurement of trunk muscle activity was shown to be poorer (ICC 0.18-0.97), which may be due to variable electrode placement and the use of inexperienced therapist who may not be experienced in anatomical palpation and electrode placement (Danneels et al. 2001).

Both studies suggest spinal musculature to be reliably replicated using sEMG, however reliability of abdominal musculature is unclear. Numerous studies have investigated abdominal musculature previously, using fine wire EMG, especially of TrA (Claus et al. 2009a; Hodges et al. 2003b; Tsao and Hodges 2008). Marshall and Murphy (2003) investigated if similar results could be reliably attained through the use of sEMG. A cohort of 20 healthy male subjects (age 19.5±2 years, BMI 22.4±2 $kg.m^{-2}$) were recruited, however only 16 subjects demonstrated feed-forward activation of TrA therefore only the data for these subjects were reported. sEMG of TRA/IO, EO, RA and deltoid were evaluated on 2 occasions, 2 weeks apart. sEMG was found to be comparable with intra-muscular EMG recordings in TrA/IO (with regard to feed-forward activation), which was reproducible at 2 weeks. These results may not be indicative of the wider general population, such as CLBP, as the low BMI scores suggest reduced adipose tissue in the abdominal region. It appears from these studies that adipose tissue is a key consideration of trunk muscle activity recordings and BMI should be considered in future investigation. Additionally the cohort consisted entirely of males thus the extent to which these findings may be replicated in a female cohort is unknown.

There is also suggestion that sub-maximal voluntary contractions (SMVC) may be more valuable and reliable in CLBP populations compared to the use of maximal voluntary contractions (MVC) (Allison et al. 1998; Dankaerts et al. 2004; Larivière et al. 2002; O'Sullivan et al. 1998). The rationale for this is explained in detail in section 6.7.2.

A review of 38 sEMG studies investigating reliability and validity of sEMG identified 30 studies reporting differences in trunk muscle activation (either increased or decreased activity levels) between LBP and healthy subjects. These findings suggest that subgroup classification is warranted in future research to understand where these differences lie (Mohseni-Bandpei et al. 2000). An aim of the current study is to evaluate trunk muscle activity in defined subgroups of NSCLBP during functional tasks to determine whether subgroup differences exist with regard to muscle activation. The current literature suggests sEMG to be an appropriate methodological approach for this purpose.

In summary, sEMG appears to be a reliable tool for measurement of back musculature. sEMG of the abdominal muscles is less clear, with TrA/IO demonstrated to be reliable in static postures with upper

limb movement, however reliability of abdominal muscle activity during functional tasks is unknown. Despite these limitations sEMG remains the most widely used and user-friendly approach to muscle activity recording in circumstances where fine-where EMG is impractical due to logistical, and potentially ethical, reasons. For this reason sEMG is to be incorporated within the methodology of this study to provide an understanding of muscle activity during functional tasks.

2.7 Summary of the Problem of NSCLBP

NSCLBP is acknowledged to be a complex interplay of biopsychosocial factors and the ability to subclassify this heterogeneous group into distinct homogeneous sub-groups is a key priority for back pain research and clinical practice (Foster et al. 2011). The MDCS proposed by O'Sullivan (2005) considers both physical presentation and psychosocial factors to comprehensively sub-group NSCLBP and has an established evidence base detailing its reliability for clinical identification between clinicians, and differences in spinal kinematics and muscle activity in static postures.

Although acknowledged that underlying MCI and maladaptive movement patterns may be a primary driver for pain in a significant number of individuals, it is currently unknown whether these patients will adopt the same pain provocative postures during functional tasks. Addressing this research question would enable specific functional interventions to be developed to re-educate maladaptive behaviours in specific MCI subgroups.

It is also clear that further investigation into the variability of movement strategies, as well as performance of functional activities in NSCLBP populations is required, incorporating both kinematic and EMG data. This thesis aims to address these research questions through evaluation of spinal kinematics and muscle activity during a battery of functional tasks in NSCLBP subjects, subclassified using the MDCS.

3 AIMS, OBJECTIVES AND HYPOTHESES

3.1 Aims of the Thesis

To investigate differences in biomechanical behaviour of the spine during functional tasks between the two MCI subgroups of NSCLBP subjects (FP and AEP) and healthy individuals three distinct investigations were planned. The first investigation involved a systematic review of the reliability and validity of all currently utilised spinal marker sets to inform the development of a novel marker set for the main study. The second investigation was a preliminary study to establish the intra-rater and between-day reliability of functional movements in healthy individuals to evaluate the variability of measuring repeated spinal movement. Finally, the main investigation involved the evaluation of: spinal kinematics during static postures, full ROM and functional tasks; and trunk muscle activity during functional tasks, between the MCI subgroups (AEP and FP) and healthy individuals. The overall aim of this thesis is to better understand the differences in MCI NSCLBP subgroups to inform targeted interventions.

3.2 Objectives

3.2.1 Systematic Review

Objective:
To review all literature utilising a spinal marker set to determine spinal measurement using three-dimensional motion analysis and determine which studies have previously validated the spinal marker sets used.

3.2.2 Preliminary Study

Objective:
To investigate within-day (intra-rater) reliability and between-day (test re-test) reliability of a novel spinal marker set for determination of sagittal spinal angle in six spinal regions during a series of functional tasks in healthy individuals.

3.2.3 Main Study

Objective 1
To investigate whether there is a difference in sagittal spinal angle between MCI subgroups of NSCLBP subjects and healthy controls in six spinal regions during usual standing and usual sitting.

Objective 2
To investigate whether there is a difference in sagittal spinal angle between MCI subgroups of NSCLBP subjects and healthy controls in six spinal regions during full ROM (flexion and extension)

Objective 3
To investigate whether there is a difference in sagittal spinal angle between MCI subgroups of NSCLBP subjects and healthy controls in six spinal regions during a series of functional tasks.

Objective 4
To investigate whether there is a difference in trunk muscle activity measured by means of surface electromyography (TrA/IO, EO, LM, longissimus thoracis (LT)) between MCI subgroups of NSCLBP subjects and healthy controls during a series of functional tasks.

3.3 Null Hypotheses

3.3.1 Preliminary Study

Null Hypothesis 1

There is no correlation between the within-day kinematic measurement scores (intra-rater reliability). When a correlation of ICC>0.80 is reached, the null hypothesis will be rejected (Landis and Koch 1977).

Null hypothesis 2

There is no correlation between the between-day kinematic measurement scores measured by a single-rater on different days (test re-test reliability). When a correlation of >0.80 is reached, the null hypothesis will be rejected (Landis and Koch 1977).

3.3.2 Main Study

Null Hypothesis 1

There will be no difference in sagittal spinal angles between MCI subgroups of NSCLBP subjects and healthy controls in six spinal regions during usual standing and usual sitting.

Null Hypothesis 2

There will be no difference in sagittal spinal angles between MCI subgroups of NSCLBP subjects and healthy controls in six spinal regions during full ROM (flexion and extension)

Null Hypothesis 3

There will be no difference in sagittal spinal angles between MCI subgroups of NSCLBP subjects and healthy controls in six spinal regions during a series of functional tasks.

Null Hypothesis 4

There will be no difference in trunk muscle activity measured by means of surface electromyography (TrA/IO, EO, LM, LT) between MCI subgroups of NSCLBP subjects and healthy controls during a series of functional tasks.

4 SYSTEMATIC REVIEW

Title: A Comparison of Spinal Measurement Marker Sets using Optoelectronic Devices: A Systematic Review

4.1 Introduction

3D optoelectronic motion analysis systems devices are often considered to be the 'gold standard' for direct, non-radiological, spinal movement measurement due to the ability to record spinal movement in real-time to a high degree of accuracy (Pearcy and Hindle 1989). These systems are non-invasive and generally have little negative influence on movement patterns and motor control strategies (Cutti et al. 2005), thus are considered a key tool to explore spinal motion in a laboratory setting. However, to date few research articles explore, or reference, reliability and validity of 3D optoelectronic motion analysis spinal marker sets.

In the absence of a consistent approach to spinal measurement, drawing comparisons between studies becomes increasingly difficult, especially when utilising established methodologies to develop future research protocols. Investigations into spinal movement using 3D optoelectronic devices need to identify a clear valid methodological framework with reported reliability and validity to ensure a consistent and comparable approach.

There is evidence to suggest the accuracy of 3D optoelectronic motion analysis systems to be high, with errors reported to be approximately ± 2° (Pearcy et al. 1987) during functional movements. Similarly, 3D motion analysis for spinal motion has been shown to be closely correlated with radiological approaches for lumbar movement (Gracovetsky et al. 1995; Pearcy et al. 1984, 1985). Reliability of marker sets can be established either by comparison to a number of different marker sets or by comparing the marker set to a 'gold standard' instrument simultaneously (i.e. radiology imaging techniques such as plain film x-ray or fluoroscopy).

In order to demonstrate accuracy spinal marker placement must accurately reflect the position of the underlying spinous processes of the vertebrae, thus the influence of soft tissue artefact must also be considered with regard to reliability (Cutti et al. 2005; Vergara et al. 2006). Despite no single spinal palpation approach being identified as being superior to another (Haneline and Young 2009) anatomical positioning of marker placement has been found to be consistent when used by the same operator (Leigh et al. 2014). Experienced manipulative therapists have been demonstrated to

accurately palpate radiologically identified spinous processes (Harlick et al. 2007); and physiotherapists demonstrate good repeatability with regard to spinal palpation and are more reproducible in palpating spinal levels than students (Billis et al. 2003). Leigh et al. (2014) identified a physiotherapist with no previous exposure to 3D motion analysis to demonstrate reliability levels comparable to an experienced biomechanist (8 years experience) with regard to marker placement (within-tester >0.90, between tester >0.85) suggesting anatomical knowledge to be an important factor in consistency of marker placement. However, inter-tester reliability of marker placement has been previously identified as a potential error source when using Vicon® (Gorton et al. 2009).

Despite this previous literature establishing reliability of the optoelectronic systems and marker placement accuracy, few articles evaluate the reliability of spinal marker sets.

4.2 Objectives

The primary aim of this review was to identify, using the PRISMA statement (Moher et al. 2009), all studies evaluating reliability or validity of 3D optoelectronic spinal marker sets. The secondary aim was to identify all articles incorporating an optoelectronic spinal marker set within the methodology to evaluate whether the approach used has been tested for reliability and validity.

4.3 Methods

4.3.1 Search Process

A PICO (Population, Intervention, Comparison, and Outcome) approach was used (Sayers 2008). The population was defined as the spinal regions being investigated (e.g. lumbar, thoracic). The intervention was 3D motion analysis (optoelectronic devices) and the outcome was spinal measurement via 3D kinematics. Searches were conducted using the following electronic databases: CINAHL (via EBSCO), Medline (via Ovid), EMBASE, AMED, Scopus and The Cochrane Library. A physiotherapy database, PEDro, was also manually searched using the keyword ‘kinematic’. Keywords included ‘spine’, ‘trunk’, ‘thoracic’, ‘lumbar’, ‘kinematic’, ‘biomechanics’, ‘movement’ and ‘motion’. See Appendix III for the search strategy used in each of the databases. All databases were searched through the full history of the database to July 2011. The search was re-run in April 2013 on all databases except for PEDro. This was due to the database not allowing for time filters and was therefore deemed too time intensive to search manually. Bibliographies of all studies and

systematic reviews were searched by hand. Articles included in this systematic review were published up to and including 23rd April 2013.

4.3.2 Eligibility Criteria

Full text English language studies which used 3D optoelectronic devices to record spinal posture or movement kinematics using reflective markers.

Exclusion criteria for the review was:

- not an optoelectronic device (e.g. electrogoniometer, electromagnetic device, finite element study, CT, MRI, fluoroscopy, potentiometer, ultrasound, goniometer, flexicurve)
- cadaveric, post-mortem or in-vitro study
- kinetics as only outcome measure
- non-human / animal studies
- respiratory kinematics (e.g. thoracic expansion)
- cervical spine (not thoracic / lumbar)
- intra-operative kinematics
- 2D kinematics
- pelvis only
- trunk inclination / lean / yaw / roll / pitch as outcome measures
- paediatric (<18 years)
- non-peer reviewed articles
- conference proceedings / book chapters

Articles were also excluded if the paper was not available in the English language, due to lack of access to a translation service.

4.3.3 Critical Appraisal

Critical appraisal was undertaken by two reviewers using the 'Critical Appraisal Tool (CAT) for studies testing the validity and reliability of objective clinical tools', as described by Brink and Louw (2012). This tool was selected as it has been previously used in studies evaluating the reliability and validity of three-dimensional spinal posture measuring instruments (Brink et al. 2011). An outline of

the tool is detailed in Appendix III. In brief the CAT is composed of 13 items to assess the impact of each item on the quality of the methodological process (Brink et al. 2011).

4.3.4 Data Analysis

The initial title and abstract screening was completed by two reviewers (RH and VS). Any disagreements were discussed to ensure consistency in interpretation of scores.

4.4 Results

4.4.1 Study Selection

Initial search – March 2011

9078 studies were identified. 1032 articles were removed as duplicates. 6626 were excluded from title and abstract screening. If the article was unable to be conclusively excluded from the abstract due to insufficient information in the methodology the full text was sourced. Full texts for the remaining 1418 articles were sourced, however 2 articles were unable to be sourced from the British Library or available online and were therefore excluded from the study. 1122 studies were excluded by full text. 296 remaining articles were identified as fitting the inclusion criteria. Following a manual screen of the reference lists of these articles a further 10 references were sourced which met the systematic review inclusion criteria.

Additional Search – April 2013

2773 studies were identified. 575 articles were removed as duplicates. An additional 38 articles were highlighted as duplicates from the previous search and were removed. 1905 articles were excluded from title and abstract screening. Full texts for the remaining 255 articles were sourced. 3 articles were unable to be sourced from the British Library or available online and were therefore excluded from the study. 161 studies were excluded by full text. 91 remaining articles were identified as fitting the inclusion criteria. Following a manual screen of the reference lists of these articles a further 3 references were sourced which met the systematic review inclusion criteria.

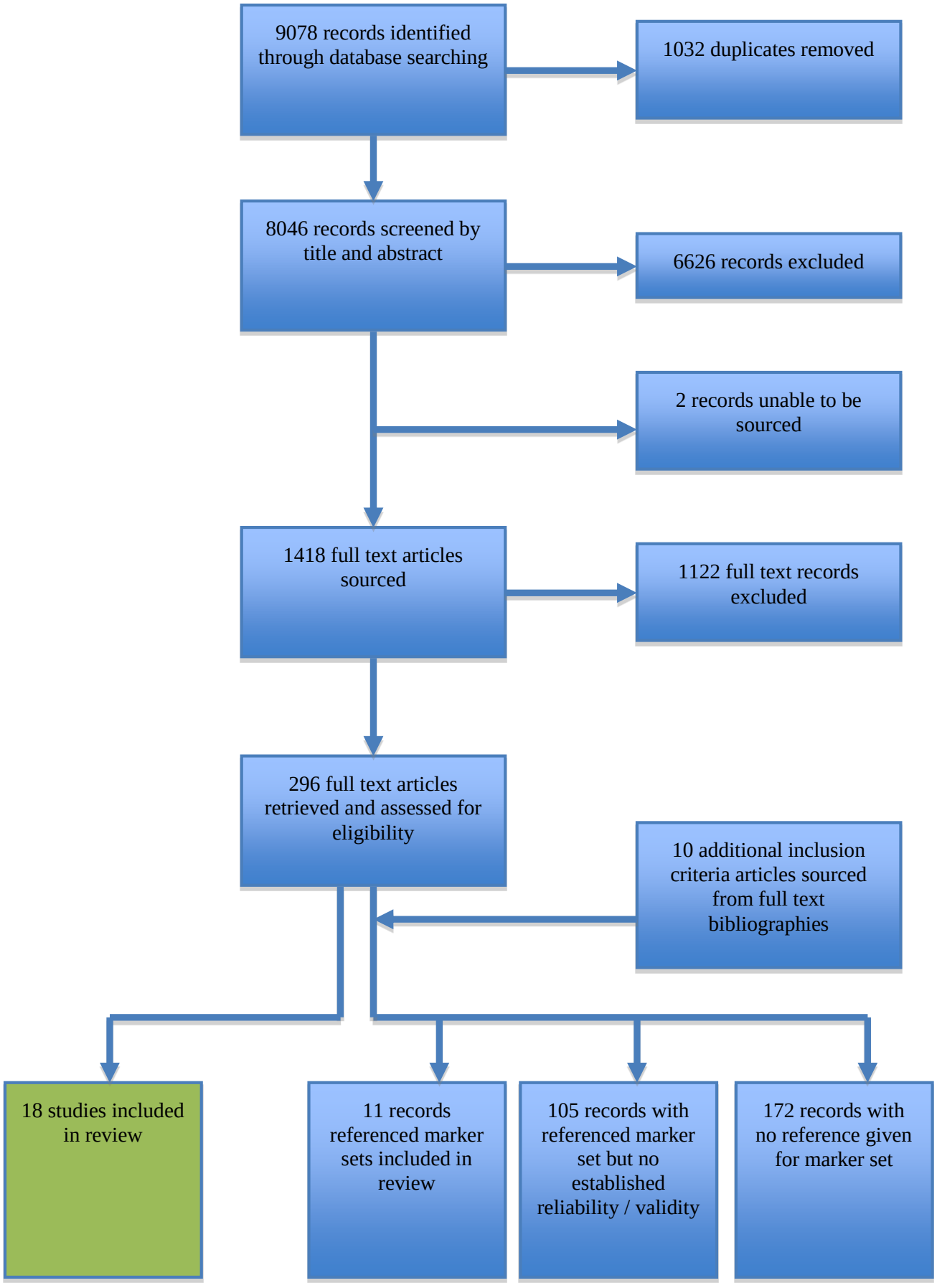


Figure 2: Flow diagram of the systematic review screening process (initial search)

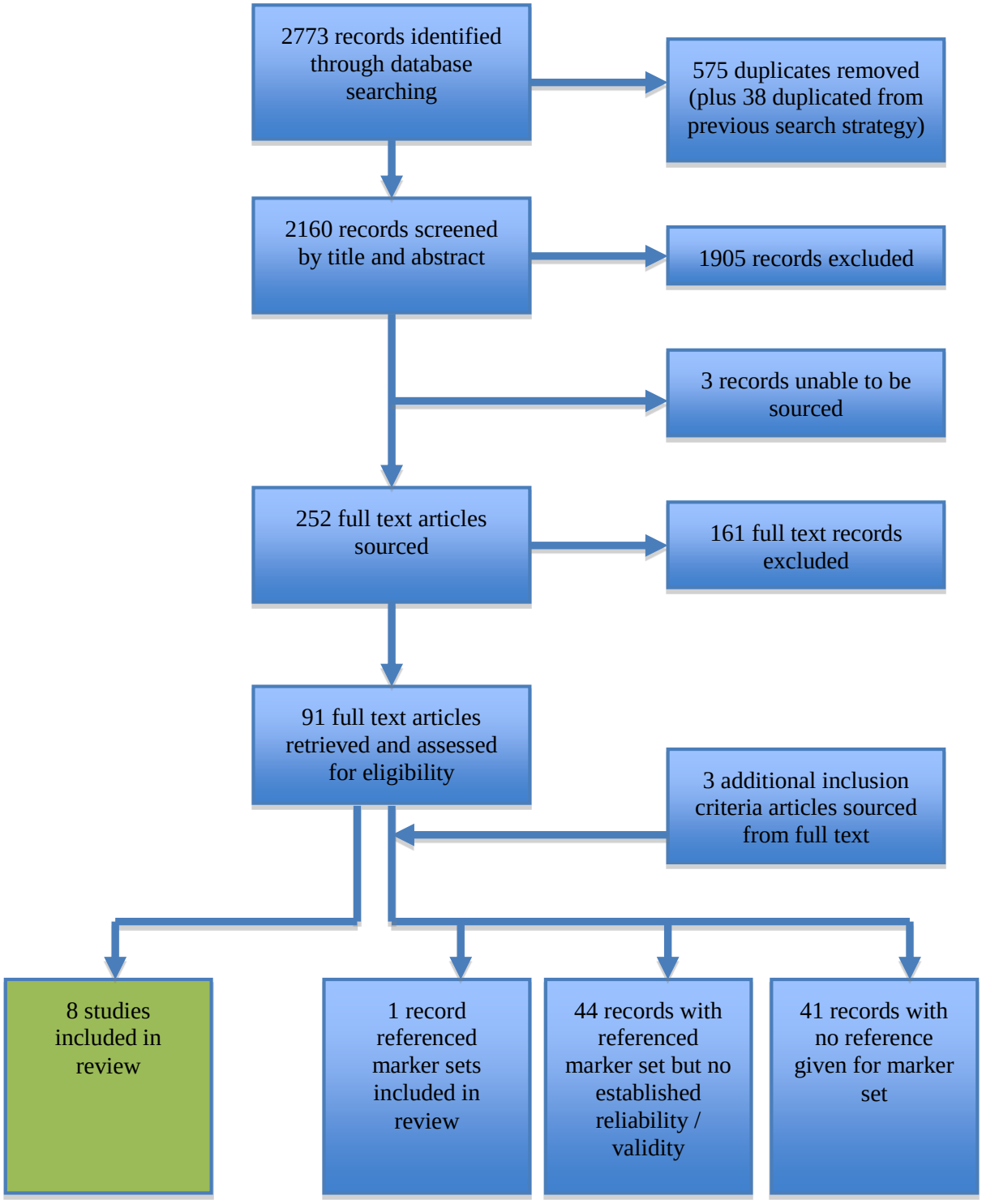


Figure 3: Flow diagram of systematic review screening process (additional search)

4.4.2 Analysis of Studies

Initial Search – March 2011

Eighteen articles were identified as exploring reliability and/or validity of a spinal marker set. Of the remaining 286 articles that used spinal marker sets (but did not primarily evaluate reliability and/or validity), 11 articles referenced an approach that had previously evaluated for reliability and/or validity of spinal movement. One-hundred-and-five articles referenced the spinal marker set approach used, however when the full text was sourced for these references, no published reliability or validity for spinal movement was reported. The remaining 172 articles provided no reference for the marker set used (Figure 2).

Additional Search – April 2013

Eight articles were identified as exploring reliability and/or validity of a spinal marker set. Of the remaining 86 articles that used spinal marker sets (but did not primarily evaluate reliability and/or validity), 1 article referenced an approach that had previously evaluated for reliability and/or validity of spinal movement. 44 articles referenced the spinal marker set approach used, however when the full text was sourced for these references, no published reliability or validity for spinal movement was reported. The remaining 41 articles provided no reference for the marker set used (Figure 3). Bibliographies of all included studies and systematic reviews were searched by hand. An additional 3 articles were identified through this process (Figure 3).

4.4.3 Final Full-text Article Screening

Twenty-six articles were identified for inclusion in the review following the initial and additional search. Three of these articles were omitted from the final screening results due to 2 articles providing insufficient data to screen using the CAT (LaFiandra et al. (2003) and Armour Smith et al. (2011)) and variability (rather than reliability) being the primary focus of a further study (Leardini et al. 2011). Additionally the Armour Smith et al. (2011) study was also highlighted as a variability study. Twenty-three eligible full text papers were screened using the CAT and included in the final analysis. The aim of 15 studies was to test reliability of the marker set and methodological approach to assess spinal movement (Anderson 2011; Cheng et al. 2013; Chockalingam et al. 2005; Graci et al. 2012; Hidalgo et al. 2012; Levine and Whittle 1996; O'Sullivan and Clifford 2010; Schache et al. 2002; Taylor et al. 2001; Taylor et al. 1996; Vanneuville et al. 1994; Whittle and Levine 1997; Williams et al. 2010; Wong and Wong 2009; Wong and Wong 2008).

The aim of 4 studies was to evaluate the validity of a spinal marker set for measuring spinal movement (Leardini et al. 2009; Ranavolo et al. 2013; Simcox et al. 2005; Zhang et al. 2003). Four studies evaluated both reliability and validity by using human subjects to measure 3D spinal movement and comparing to a reference standard (Andreoni et al. 2005; Garrido-Castro et al. 2012; Joyce et al. 2010; O'Sullivan et al. 2012b).

4.4.4 Synthesis of Results

Table 3 summarises the protocols used, including marker sets and movements evaluated, for each reviewed study.

Table 4 summarises the motion analysis system evaluated, type of reliability / validity, reference standard and statistical procedure for each reviewed study.

Table 5 summarises the methodological quality appraisal results of the reviewed studies for each item outlined by the CAT (Brink and Louw 2012).

Table 3: Summary of the protocols used, including marker sets and movements evaluated, for each reviewed study

Author / Year	Motion Analysis system	Number of Cameras	Data sampling rate	Marker set for trunk	Study population	Spinal movement evaluated	Outcomes measured
RELIABILITY							
Anderson et al, 2011	Vicon® (*m-series)*	6	(Not reported)	Plug-in-gait' marker set	10 individuals with rotator cuff pathology (6M, 4F)	Thoracic extension, lateral flexion in sitting	Peak thoracic extension, lateral flexion (to affected and unaffected side)
Cheng et al, 2013	EVaRT 4.2 (Motion Analysis Corporation®)	8	60Hz	C7, T4, L1, L3, L5, ASIS', PSIS', acromions	18 healthy subjects (8M, 10F)	Sagittal flexion and extension lumbar spine, coronal side bending and trunk circumduction	Workspace' of C7, L1 and knee relative to local pelvic system
Chockalingam et al, 2005	Motion Analysis Inc.®	5	120Hz	Every other vertebral spinous process from C7 to S3	3 healthy male subjects	Right and left lateral flexion	Spinal angle between each marker on the spine, e.g. C7-T2, T2-T4
Graci et al, 2012	Vicon® Nexus	8	120Hz	Acromia, C7, T2, T10, jugular notch, xiphoid process, iliac crests, ASIS', PSIS'	19 healthy subjects (10M, 9F)	Single right leg squat	trunk relative to pelvis in sagittal, frontal, transverse planes
Hidalgo et al, 2012	ELITE-BTS®	8	200Hz	Spinous processes of S2, L3, T12, T7, C7, ASIS', Acromio-clavicular joint bilaterally	25 healthy subjects (10M, 15F), 25 NSCLBP subjects (12M, 13F)	Trunk flexion, lateral side bending, rotation, trunk flexion with right rotation in sitting	upper / lower thoracic, upper / lower lumbar, total lumbar, shoulder segment ROM (degrees)
Levine & Whittle, 1996	Vicon®	5	50Hz	ASIS', mid PSIS marker, rig of 2 markers on sacrum (approx S2), T12/L1	20 healthy female subjects	Standing and walking, maximum posterior and anterior pelvic tilt in standing	(pelvic tilt) and lumbar lordosis
O'Sullivan and Clifford, 2010	CODA™	2	200Hz	T11, L1, 'virtual' L4, 2.5cm lateral to L4 spinous process, pelvic 'wand' (with markers reflecting position of ASIS', PSIS')	12 healthy subjects (5M, 7F)	Usual sitting posture, posterior pelvic tilt in sitting (maximum lumbar flexion), anterior pelvic tilt in sitting (maximum lumbar extension)	Total ROM (degrees), usual sitting posture (degrees, and degrees from end-range flexion) for upper lumbar and lower lumbar
Schache et al, 2002	Vicon® 370	6	200Hz	ASIS', mid-point between the PSIS', rigid cluster of 3 markers at T12 level (based on Pearcy et al's (1987) protocol)	14 healthy subjects (11M, 3F) (active runners >20km per week)	Treadmill running (no incline, 4.2m/sec)	Trunk and lumbar spine lateral bend, flexion-extension, axial rotation
Taylor et al, 2001	Peak 3D	2	50 fields per second	8 markers: rigs on sacrum and L1, PSIS'	26 healthy subjects (12M, 14F) (undergraduate students)	Lumbar lateral flexion, lumbar flexion and extension, lumbar axial rotation	Lumbar movement relative to global reference frame
Taylor et al, 1996	Peak 3D	2	50 frames per second	lightweight orthoganol rigs placed on the sacrum and L1	16 healthy subjects (6M, 10F)	Treadmill walking at self-selected (or 60% of self-selected) speed over 10 minutes	Lumbar spine angles (degrees) relevant to pelvis
Vanneuville et al, 1994	Mac Reflex®	2	Every 2/100ths of a second	T1, T7, T12, L1, L3, L5	6 healthy subjects (4M, 2F) (university students trained in gymnastic techniques)	Flexion, extension, lateral flexion, lateral rotation	Spinal displacement in 3 orthoganol planes of movement
Whittle & Levine, 1997	Vicon®	(Not reported)	(Not reported)	(3 different lumbar configurations compared)	28 healthy female subjects	Gait	Lumbar lordosis
Williams et al, 2010	Vicon® 370	9	100Hz	ASIS', PSIS', 8 markers from S1 up the spine at 60mm intervals	13 healthy subjects (11M, 2F)	Upright standing, full flexion, position about to lift an object	Lumbar lordosis (whole lumbar spine, lower lumbar spine) - during flexion and lifting
Wong and Wong, 2009	Vicon® 370	6	60Hz	C7, T3, T5, T7, T9, T11, L1, L3, L5, S2, ASIS, left T10, Right T10 ' (to derive thoracic axis system)	9 healthy subjects (3M, 6F)	Upright sitting and standing, left and right lateral bending, forward flexion, stand-to-sit	Sagittal & coronal from intersegmental angle - thoracic region C7-T1. T11-S2 for lumbar region
VALIDITY							
Joyce et al, 2010	MX-F20 Vicon®-Peak	10	250Hz	Sternum, T10, L1	1 male golfer (handicap of 7)	Flexion, extension, lateral bending, rotation + 10 maximal effort golf swings and anatomical position	Cardan angles - shoulders relative to pelvis, lower thorax relative to pelvis
Leardini et al, 2009	Vicon® 612	8	100Hz	C7, T2, T8, T10, L5, sacrum, PSIS', ASIS'	10 healthy subjects (5M, 5F)	Activities of Daily Living: walking, chair rising/sitting, step-up/down, trunk movements inc. flexion, bending, axial rotation	ROM axial trunk rotataion, lateral bending, flexion/extension in the laboratory and pelvis reference frames
Ranavolo et al, 2013	SMART-E®	8	120Hz	Every spinous process from C6-S1	10 healthy subjects (5M, 5F)	Upright standing, full trunk flexion, full trunk lateral inclination	Comparison of whole-spine resulting curves (polynomial interpolations of vertebral centroids) using differing numbers of markers
Simcox et al, 2004	Eva HiRes™	6	60Hz	C7, sternum, T10	1 healthy subject (gender not reported)	Sit-stand-sit and walking (self-selected pace, 10m)	Trunk relative to laboratory coordinate system (LCS)
Wong and Wong, 2008	Vicon® 370	(Not reported)	(Not reported)	C7, T3, T5, T7, T9, T11, L1, L3, L5, S2, ASIS'	3 healthy subjects (gender not reported)	Left & right lateral bending, forward flexion (from upright sitting to slouched sitting)	Sagittal & coronal from intersegmental angle - thoracic region C7-T1. T11-S2 for lumbar region
Zhang et al, 2003	Vicon® 250	5	120Hz	7 spinous processes: C7, T7, and L2–S1	10 healthy subjects (5M, 5F)	Lifting a load from the floor to a shelf at about the chest height	Internal vertebral rotation and externally estimated inter-segmental motion for T7, L2,3,4,5
RELIABILITY AND VALIDITY							
Andreoni et al, 2005	ELITE®	8	100Hz	3 markers on each vertebra from T11 - S1, ASIS', PSIS'	10 healthy male subjects	Flexion, extension, right bending, left bending, right rotation, left rotation	Position and rotation of each vertebrae from computation of euler angels and indentifying anatomical axes
Garrido-Castro et al, 2012	UCOTrack©	4	50 frames per second	shoulder bone', C7, L4, 10cm below C7, midpoint between C7 and L4, 10cm above L4, ASIS'	40 Ankylosing spondylitis subjects (36M, 4F), 20 healthy subjects (10M, 10F)	Flexion, extension, lateral flexion, rotational movements	Peak value of each movement for each ROM for dorsal and lumbar spine during flexion/extension, lateral flexion, rotational movements
O'Sullivan et al, 2012b	CODA™	2	200Hz	PSIS', spinous process of L1, 5cm lateral to L3, sacral attachment (x2 markers)	12 healthy subjects (3M, 9F)	Usual standing, forward bending to knees, forward bending to lower leg,lift/lower box, lowering box with rotation, wiping a bench, sweeping the floor with a brush, sit-to-stand, usual sitting posture, flexed / extended sitting, facilitated 'neutral' posture, typing on a laptop, reading a book, writing in a notebook, trunk rotation and trunk side flexion in sitting and standing.	Mean flexion & / or peak flexion (bending and lifting tasks) during tasks, total ROM flex/ext/rotation/side flexion in sitting & standing lower lumbo-pelvic region

Table 4: Summary of the motion analysis system evaluated, type of reliability / validity, reference standard and statistical procedure for each reviewed study

Author, Year	Motion Analysis System	Statistical Analysis	Type of reliability	Time interval	Type of validity	Reference standard
RELIABILITY						
Anderson et al, 2011	VICON Systems *m-series*	Paired t-test and ICC	Intra-rater	Between-day	N/A	N/A
Cheng et al, 2013	EVaRT 4.2	Pearson correlation coefficients and ICC	Test re-test	Between-day	N/A	MATLAB mathematical model
Chockalingam et al, 2005	Motion Analysis Inc.		Inter-rater	Within-day	N/A	Potentiometer-based electrogoniometer
Graci et al, 2012	VICON Nexus	Independent samples t-test and ICC	Intra-rater	Between-day	N/A	N/A
Hidalgo et al, 2012	ELITE-BTS	ICC, SEM and minimal detectable change (MDC)	Test re-test	Between-day	N/A	N/A
Levine and Whittle, 1996	Vicon	ICC	Intra-test	Within-day	N/A	N/A
O'Sullivan and Clifford, 2010	CODA™	ICC	Intra- and inter- rater	Within- and Between-day	N/A	N/A
Schache et al, 2002	VICON 370	Adjusted coefficient of multiple correlation	Intra-rater	Within- and Between-day	N/A	N/A
Taylor et al, 2001	Video-based Peak 3D	ICC and Pearson Correlation Coefficient	Test-retest	Within- and Between-day	N/A	N/A
Taylor et al, 1996	Peak 3D	ICC, Fishers r to z transformation and One way ANOVA	Within-subject	Within-day	N/A	N/A
Vanneuville et al, 1994	Mac Reflex	Not reported	Test re-test	Within- and Between-day	N/A	N/A
Whittle and Levine, 1997	Vicon	ICC and Pearson Correlation Coefficient	Intra-rater	Within-day	N/A	N/A
Williams et al, 2010	Vicon 370	Coefficient of multiple correlation and RMSE	Test re-test	Within-day	N/A	Shapetape™ Fibre-optic system
Wong and Wong, 2009	Vicon 370	ICC and mean RMS (angular velocity)	Intra-test	Within-day	N/A	Tri-axial accelerometer and 3 uniaxial gyroscopes
VALIDITY						
Joyce et al, 2010	MX-F20 Vicon-Peak	Adjusted coefficient of multiple correlation, mean absolute variability	N/A	Within-day	Concurrent validity	High-speed video camera (Sony HDRFX7)
Leardini et al, 2009	VICON 612	One-way ANOVA	N/A	Within-day	Concurrent validity	8 trunk kinematic models
Ranavolo et al, 2013	SMART-E system	Co-efficient of multiple correlation, ANOVA and post-hoc tests	N/A	Within-day	Concurrent validity	Radiographic assessment
Simcox et al, 2004	Eva HiRes	RMSE and cross-correlations	N/A	Within-day	Concurrent validity	Gyroscope and 2D accelerometers
Wong and Wong, 2008	VICON 370	Mean RMS and ICC	N/A	Within-day	Concurrent Validity	Tri-axial accelerometer
Zhang at al, 2003	Vicon 250	Criterion of convergence and RMSE	N/A	Within-day	Construct validity	Mathematical models
RELIABILITY AND VALIDITY						
Andreoni et al, 2005	ELITE	Pearson correlation coefficient	Intra- and inter-rater	Within- and Between-day	Concurrent validity	Compared to literature (White and Panjabi)
Garrido-Castro et al, 2012	UCOTrack	ICC and SEM	Test re-test	Within- and Between-day	Construct validity	Conventional metrology results and structural damage radiological scores
O'Sullivan et al, 2012b	CODA™	Spearmans rank correlation coefficient and coefficient of determination (r^2)	Within-subject	Within-day	Concurrent validity	Bodyguard™ strain guage

Table 5: Summary of the methodological quality appraisal results of the reviewed studies for each item in the Critical Appraisal Tool

Author / Year	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Item 12	Item 13
RELIABILITY													
Anderson et al, 2011	Y	N	-	-	N	Y	-	Y	-	Y	-	Y	Y
Cheng et al, 2013	N	N	-	-	N	Y	-	Y	-	Y	-	Y	N
Chockalingam et al, 2005	Y	N	-	Y	-	N	-	N	-	Y	-	Y	Y
Graci et al, 2012	Y	N	-	-	N	-	-	N	-	Y	-	Y	Y
Hidalgo et al, 2012	Y	N	-	-	N	N	-	Y	-	Y	-	Y	Y
Levine & Whittle, 1996	Y	N	-	-	N	N	-	Y	-	Y	-	Y	Y
O'Sullivan and Clifford, 2010	Y	Y	-	N	N	N	-	N	-	Y	-	Y	Y
Schache et al, 2002	Y	N	-	-	N	-	-	Y	-	Y	-	Y	Y
Taylor et al, 2001	Y	Y	-	-	N	-	-	Y	-	Y	-	Y	Y
Taylor et al, 1996	N	N	-	-	N	N	-	Y	-	N	-	Y	Y
Vanneuville et al, 1994	Y	N	-	-	-	-	-	Y	-	Y	-	Y	N
Whittle & Levine, 1997	Y	N	-	-	N	N	-	N	-	Y	-	Y	Y
Williams et al, 2010	Y	N	-	-	N	Y	-	Y	-	Y	-	Y	Y
Wong and Wong, 2009	Y	N	-	-	-	-	-	N	-	Y	-	Y	Y
VALIDITY													
Joyce et al, 2010	N	N	Y	-	-	-	Y	-	Y	Y	Y	Y	Y
Leardini et al, 2009	Y	N	Y	-	-	-	Y	-	Y	Y	Y	Y	Y
Ranavolo et al, 2013	Y	N	Y	-	-	-	Y	-	Y	Y	Y	Y	Y
Simcox et al, 2004	N	N	Y	-	-	-	Y	-	Y	Y	Y	Y	Y
Wong and Wong, 2008	N	N	N	-	-	-	N	-	Y	N	N	Y	Y
Zhang et al, 2003	Y	N	Y	-	-	-	Y	-	Y	N	Y	Y	Y
RELIABILITY AND VALIDITY													
Andreoni et al, 2005	Y	Y	N	N	N	-	N	Y	N	Y	Y	Y	Y
Garrido-Castro et al, 2012	Y	Y	Y	-	N	N	Y	Y	Y	Y	Y	Y	N
O'Sullivan et al, 2012	Y	N	Y	-	N	N	Y	Y	Y	Y	Y	Y	Y

Key: Y = Yes, N = No, - = N/A

4.4.5 Methodological Quality Appraisal

Table 5 summarises the findings from the critical appraisal of the article in relation to the reported reliability and validity. The items referred to are described in detail in Appendix III.

Item 1: Subject sample descriptions were provided for almost all studies except: Cheng et al. (2013); Simcox et al. (2005); Taylor et al. (1996); Joyce et al. (2010); and Wong and Wong (2008) where insufficient information regarding the subject sample was provided.

Item 2: Few articles outlined the qualification (or competence) of the raters performing the marker set placement. However these aspects of the methodology were suitably reported within the methods of Taylor et al. (2001), O'Sullivan and Clifford (2010), Andreoni et al. (2005) and Garrido-Castro et al. (2012).

Item 3: The reference standard was explained for all articles reporting validity except for Wong and Wong (2008) and Andreoni et al. (2005) where the reference standard was not clearly reported.

Item 4: Only 3 articles evaluated inter-rater reliability (Andreoni et al. 2005; Chockalingam et al. 2005; O'Sullivan and Clifford 2010) of which only 1 study (Chockalingam et al. 2005) stated that raters were blinded to each others findings.

Item 5: This item referred to whether raters were blinded to their own findings. This was either not reported or not relevant to each of the reliability studies evaluated.

Item 6: The order in which the examination was varied was reported only in 4 of the evaluated articles (Anderson 2011; Cheng et al. 2013; Williams et al. 2010; Zhang et al. 2003).

Item 7: All validity studies reported the time period between the reference standard and the index test with the exception of Wong and Wong (2008).

Item 8: The stability of the marker set was reported and considered when determining the suitability of time intervals between repeated measures in some, but not all, studies.

Item 9: The reference standard was found to be independently performed in all validity studies with the exception of Andreoni et al. (2005) where although reliability is mentioned only correlations are performed.

Item 10: All studies reported clear descriptions of measurement procedures except Taylor et al. (1996), Wong and Wong (2008) and Zhang et al. (2003) where insufficient information was supplied.

Item 11: All validity studies reported clear descriptions of the measurement procedures except Wong and Wong (2008) where insufficient information regarding these procedures was supplied.

Item 12: All studies evaluated clearly explained whether any subjects withdrew from the study.

Item 13: The majority of studies used appropriate statistical methods to evaluate reliability and / or validity. Three studies however (Cheng et al. 2013; Garrido-Castro et al. 2012; Vanneuville et al. 1994) failed to provide sufficient information regarding these approaches.

4.5 Discussion

This systematic review attempted to evaluate reported reliability and validity of spinal marker sets used to evaluate spinal movement using 3D optoelectronic motion analysis techniques. Overall, the review identified that few articles report reliability and or validity of spinal marker sets and that a substantial volume of literature evaluating spinal movement utilises marker sets which are not referenced or have not been established to be reliable or valid.

Establishing reliability is complex in spinal movement as marker placement on human subjects can be influenced by error of the 3D optoelectronic system for data aquisition, human error of marker placement and variability in the performance of functional spinal movement. These 3D optoelectronic systems for data acquisition also rely on the accuracy of the data processing and analysis procedures, which need to be robust.

Of the articles evaluating reliability many were poorly documented due to a lack of detail or clarity with variable approaches to exploring reliability making it difficult to draw conclusive comparisons between studies. The main identified flaws of the reliability study were the reporting of the qualification of the person applying the markers and lack of blinding of raters. However, studies evaluating validity were generally better reported, with a greater proportion of items scoring positively using the CAT (Brink and Louw 2012).

The qualification of the person applying the markers is central to reliability and validity to enable the methodological approaches to be replicated appropriately (Bossuyt et al. 2003), therefore the limited reporting of this factor in the existing literature is of concern. Additionally the value of including articles exploring inter-rater reliability may also be called into question. Chockalingam et al. (2005) aimed to evaluate inter-rater reliability to establish the accuracy of marker placement, however the ability of the marker set to accurately record spinal movement cannot be evaluated using this approach. Coupled with the lack of detail of the raters' background (or qualifications) in marker placement, this is of limited use for future implementation. When evaluating reliability issues arise when markers are removed and replaced on the skin, thus introducing a further source of error (for example evaluating between day reliability) as it is unknown whether differences observed are due to marker placement error or the variability in movement patterns of the individual. However a strength of the Chockalingam et al. (2005) study over other studies evaluating either intra- or inter-rater reliability is that it is established that the raters were blinded to any previous measurements obtained thus reducing potential bias and subsequent study quality.

These studies are also hindered by the lack of a 'gold' reference standard for motion capture. Real-time dynamic radiographical measurements (such as fluoroscopy) are the 'gold standard' comparison for 3D optoelectronic devices when evaluating human movement, however it is acknowledged that these are relatively recent technologies. Ranavolo et al. (2013) compared 4 radiographs throughout the spinal movement which the spinal marker set, however this approach is still limited to 2D static images which can only be obtained at specific time points (rather than real-time dynamic movement evaluation). Additionally the health risks to the subject as a result of x-ray exposure remains a clear limitation.

Development of wearable technologies is fast improving. Lightweight portable devices, which can be attached directly to the skin and worn throughout the day, will also further enhance the understanding of 3D motion analysis of functional spinal movement.

4.5.1 Marker Sets

It is clear from Table 3 that a variety of approaches to spinal marker placements have been reported. The accuracy of spinal movement data obtained is directly impacted upon by the choice of marker placement. Some of the studies provide very little information regarding this. The marker placements evaluated by Taylor et al. (2001) and Taylor et al. (1996) for example are unable to be replicated due to the lack of detail regarding the methods provided. Some approaches may also be limited in their

ability to evaluate spinal movement due to a paucity of markers placed directly on the spine. Anderson (2011) for example utilises the plug-in-gait model, which is widely used for lower limb motion analysis evaluation and does not use a lumbar marker but uses T10 and C7 instead and thus may not be sensitive enough to detect subtle movement changes in the lumbar spine. This is a particular issue for designing future studies where localised sub-regions of the spine may need to be evaluated to establish between group differences (Mitchell et al. 2008)

Many marker set approaches apply markers over the spinous processes of the thoracic and lumbar spine and use pelvis markers (e.g. ASIS', PSIS') to report spinal movement relative to the pelvis position (Joyce et al. 2010; Leardini et al. 2009; Taylor et al. 1996). This approach could be argued to be preferable to those reporting spinal movement in a global co-ordinate system (Simcox et al. 2005; Taylor et al. 2001) where true movement of the spine, in relation to a fixed local co-ordinate system, such as the pelvis, cannot be clearly established.

Some approaches, such as Chockalingam et al. (2005) and Wong and Wong (2008), interpret spinal movement in a region (such as the total lumbar or total thoracic spine) as the angular change between two fixed points at either end of the region. Although this may give a consistent change in angle it may not provide much value in understanding the patterns and behaviours of the spine between such points, for example identifying changes in lumbar lordosis at a segmental level as an individual moves into flexion.

4.5.2 Limitations of the CAT

The CAT is currently of limited use with regard to some of the items. For example item 4 refers to inter-rater reliability. For the current study inter-rater reliability is of limited value as both the rater and the movement are potential variants thus the reliability of the marker set / methodological approach cannot be established. Item 6 refers to the order of examination with regard to the gold standard. Currently, the 'gold standard' is optoelectronic devices thus there is no suitable comparable measure. In future, 3D spinal marker sets using optoelectronic devices could be used concurrently with more novel radiographic techniques such as fluoroscopy which may enable gold standard comparisons to be drawn however currently item 6 is of limited value in terms of appraisal for this purpose and all items were scored as 'N/A'.

4.6 Conclusions

This study highlights that many of the spinal marker sets in use have little or no established reliability, thus inherently impacting the accuracy of the results obtained. This review has also identified that relatively spinal few marker sets in use have been suitably validated, with no clear approach to evaluating spinal marker sets being established.

Measurement of the spine is inherently complex and therefore difficult to evaluate due to participant movement variability. Establishing validity of spinal marker sets is hindered by the lack of a gold standard, however the use of fluoroscopic imaging (or similar) may be useful for validating such systems in future.

The next stage would be to evaluate the marker sets these studies evaluate to establish which may be optimal with regard to specific marker locations. Also establishing marker sets with the fewest possible number of markers to provide optimal recording would be a key research priority (Ranavolo et al. 2013).

In summary, methodological rigour in evaluating reliability and validity needs to be improved in order to enable the research community to more robustly measure dynamic spinal movement using 3D optoelectronic motion analysis devices and spinal marker sets.

5 PRELIMINARY STUDY

Title: Can a Novel 3D Optoelectronic Spinal Marker Set Accurately Measure Healthy Spinal Movement during Functional Activities? A Within-day and Between-day Comparison

Please note: Data collection for this study was performed as part of the main study protocol. Within-day reliability data collected on healthy subjects is included within the healthy control data set reported in the main study (Chapter 6).

5.1 Background

Movement analysis is frequently used to evaluate spinal movement in back pain populations, however variability of functional movement is rarely reported in healthy or back pain subjects. In order to explore potential movement dysfunction in back pain subjects, variability of movement in healthy individuals needs to be better understood (Sheeran et al. 2010). 3D motion analysis marker sets in use throughout the literature have been shown to inadequately report and reference the reliability and validity of spinal marker sets used (Chapter 4), thus limiting the ability to replicate methodologies in a robust manner. The aim of this study is to evaluate the ability of a novel marker set to measure thoracic and lumbar sagittal spinal angles during usual functional activities, within-day and between-day.

5.2 Literature Review

Chapter 4 highlighted the limited number of articles exploring reliability and validity of spinal marker sets used, despite 3D motion analysis currently being regarded as the 'gold standard' for non-radiological measurement of posture and movement (Clarke and Murphy 2014; Ugbolue et al. 2013). In the absence of a consistent approach for spinal measurement, drawing comparisons between studies becomes increasingly difficult and limits replication in the absence of clear established methodologies. Future investigation into spinal movement needs to identify a clear valid methodological framework with reported reliability to ensure a consistent and comparable approach.

Measurement of spinal movement is challenging due to vast differences in research methodologies as well as the biopsychosocial complexity of CLBP and inter-subject variability. Variability of spinal movement and postural co-ordination has been shown to be altered in individuals experiencing pain. Jacobs et al. (2009) noted that following acutely induced LBP a reduction in postural co-ordination

occurred due to a potentially reduced capability to make anticipatory postural adjustments. Conversely, in healthy individuals, variability of spinal movement during weighted lifting tasks has previously been observed to be less deterministic (i.e. more random) in healthy individuals compared to NSCLBP subjects (Dideriksen et al. 2014). It is therefore important to reliably quantify the variability of healthy human movement using this novel marker set to ensure the measurement approach is robust and sensitive to changes occurring between healthy individuals and LBP populations.

Hidalgo et al. (2012) developed a spinal marker set exhibiting good to excellent reliability of active trunk ROM in sitting in both healthy individuals and a NSCLBP group (ICC 0.70-0.96, SEM (%) 19.4-3.3). The model considers upper thoracic (C7–T7), lower thoracic (T7–T12), upper lumbar (T12–L3), lower lumbar (L3–S2) and total lumbar (T12–S2) spinal regions, however the thoracic regions are calculated via a gross angle between the C7 and T7 (upper thoracic), and T7 and T12 (lower thoracic) markers alone. The mean angle of a greater number of thoracic spinal positions could be hypothesized to more accurately represent the thoracic spinal regions, especially during functional tasks where between group differences in total angle may be more subtle. This study will evaluate whether a similar spinal marker placement approach is still reliable using a greater number of thoracic spinal markers. Although the Hidalgo et al. (2012) study supports the use of the spinal marker set for trunk ROM in sitting, whether this model is appropriate for recording usual functional activity remains to be established.

As outlined in Chapter 4, no single marker set has established reliability for evaluating both thoracic and lumbar regional spinal angles. The purpose of this study is to evaluate the ability of the novel spinal marker set and methodology to measure the consistency of functional spinal movement in healthy individuals between days. The current marker set has been developed to incorporate aspects of previously established spinal marker sets (Hidalgo et al. 2012; Vismara et al. 2010) and adding additional markers, especially in the thoracic region, to ensure that all spinal regions can be investigated. The spinal marker set developed also allows for sub-divided spinal regions to be explored. Mitchell et al. (2008) identified between group differences (NSCLBP vs. healthy) when the upper and lower lumbar spinal regions were considered when no differences in total lumbar angle were observed. Similarly Dankaerts et al. (2006c) found differences between subclassified MCI NSCLBP groups in sub-divided lumbar regions.

There is a strong evidence base for 3D motion analysis for use in evaluating joint movement. Windolf et al. (2008) report the accuracy of the Vicon® system (Vicon Motion Systems Ltd, Oxford), when adequately calibrated and undertaken in the appropriate environment, to be excellent (63±5μm) with an overall precision of approximately 15μm. Anatomical positioning of marker placement has been

found to have acceptable reliability (R > or = 0.80) in the lower limb when repeated during the same day by the same tester (measured using photographs) (Marks and Karkouti 1996), however this study established reliability using still photographs therefore it remains to be established if this finding can be replicated using 3D techniques.

Leigh et al. (2014) interestingly found that a physiotherapist with no previous experience in 3D motion analysis demonstrated reliability in the accuracy of marker placement comparable of that of an experienced biomechanist (8 years experience) (within-tester coefficient of multiple correlations (CMC) >0.90, between tester CMC >0.85). Thus it could be argued that palpatory skills and underlying anatomical knowledge may be a more important factor in consistent marker placement than previous experience of the methodological approach and equipment. Variability in anatomical marker placement between testers has been identified as the greatest cause of kinematic variability using Vicon® (Gorton et al. 2009), highlighting the importance of utilising the same tester throughout to reduce this error source.

Understanding the consistency of movement in healthy individuals across trials performed within-and between-days will aid in identifying whether the marker set is a robust approach to consistently measure regional sagittal spinal angles during functional tasks.

5.3 Aim of the Study

The aim of this study is to determine within- and between-day reliability of a novel spinal marker set during repeated functional movements in healthy subjects.

5.4 Methods

All testing was performed in a single visit at the Research Centre for Clinical Kinesiology (RCCK), School of Healthcare Studies, Cardiff University, Wales, UK. Ten healthy volunteers were recruited to the study from a convenience sample of Cardiff University staff and students (Cardiff University, Wales, UK) and all subjects recruited to this study were also recruited to the main study (Chapter 6). A repeated measures test re-test study design was employed where each subject‘s spinal movement pattern was measured across 4 trials conducted over 2 visits. These were performed more than 7 days apart to negate any potential learning effects between sessions.

Regional sagittal spinal kinematics were evaluated using a novel 3D motion analysis system (Vicon®) spinal marker set. A detailed description of the marker set development and protocol is outlined in Chapter 6. Retro-reflective markers (Vicon®, Oxford, OX2 0JB) were attached (using double-sided marker tape) over the following anatomical positions: spinous processes of C7, T2, T4, T6, T8, T10, T12, L2, L4, ASIS', PSIS', iliac crest (mid-crest, vertically aligned with the greater trochanter bilaterally) (Figure 13). Additional markers were placed on the: manubrium sterni (superior border); acromioclavicular joint (bilaterally); ulna styloid process (bilaterally); a point 10cm lateral of T12 (bilaterally), lateral knee joint line (bilaterally); and lateral malleolus (bilaterally). A headband with 4 reflective markers equally spaced was also worn. A virtual S2 marker was calculated in a novel Vicon Nexus pipeline (as described in section 5.4.2). Data was captured using a Vicon® motion analysis system (Vicon 512 Motion Systems Ltd, Oxford, OX2 0JB) at a sampling frequency of 100Hz.

The same protocol was utilised as in the main study (Chapter 6), however for the purpose of this study only the functional tasks (reach up, sitting-to-standing, standing-to-sitting, step up, step down, box lift, box replace, bend to pick up pen, return form picking up pen) were evaluated. Each task was repeated until 4 good quality trials had been recorded. Following each trial the data was observed visually in Vicon Nexus to ensure all markers were consistently present.

5.4.1 Functional Task Protocols

Sit-to-Stand-to-Sit

For the sit-to-stand task the plinth height was individually standardised to a height where the subjects' hips and knees were resting comfortably at 90 degrees (measured using a goniometer (Lafayette Instrument Co. Ltd., Lafayette, IN, USA)) with the thighs well supported on the plinth. Sit to stand was performed from a usual sitting position. The subject was instructed to sit in their usual (unsupported) sitting position on the plinth, wait for 2 seconds in standing, then return to the original position.

Figure 4: Sit-to-stand

Figure 5: Stand-to-sit

Box

To measure a standardised distance for moving the box during the rotational box task tape was placed at a distance equal to 70% of the total upper limb (UL) length from the midline of the plinth (NB: total upper limb length was measured in cm from the apex of the acromion process to the distal end of the middle phalanx of each hand). For this task the plinth was also set to the height of the individuals' greater trochanter. To perform the task a 2.5kg box was placed over the marked line to the left hand side of the plinth. The subject was instructed to stand with the plinth in front and move the box from left to right (to a position over the line to the right hand side) with the box starting and finishing facing the same direction. No specific directions regarding how to lift were given, however the subject was instructed to stand in a comfortable position and keep their feet stationary throughout the task. At the end of the task the subject return to their usual standing position.

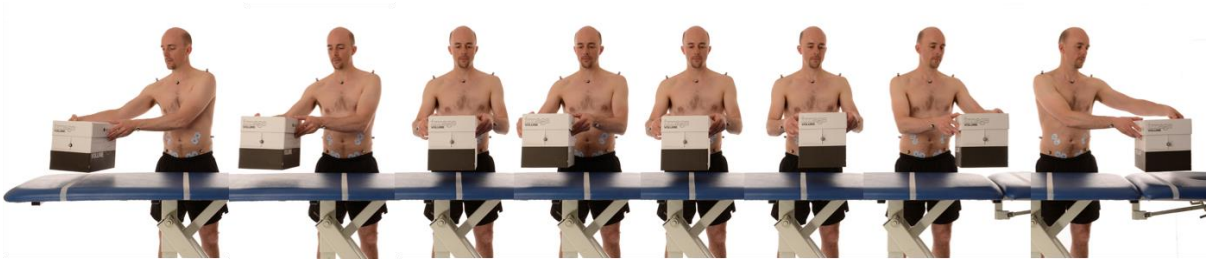


Figure 6: Box pick up and replace (rotation)

Reaching

The shelf used in the reaching task was set to the height of the ulna styloid process (right upper limb) when the shoulder was in full flexion (fully elevated). The subject stood directly in front of the custom-made shelf, with the shelf base in-line with the midline of the trunk (frontal plane). The subject placed a jar onto the shelf using their right hand, allowed the jar to rest on the shelf for 2 seconds (without releasing from their hand) and returned the jar to the original position. Feet were kept stationary throughout and the subject was instructed to keep their heels on the floor at all times. The subject also kept hold of the jar at all times throughout the task.

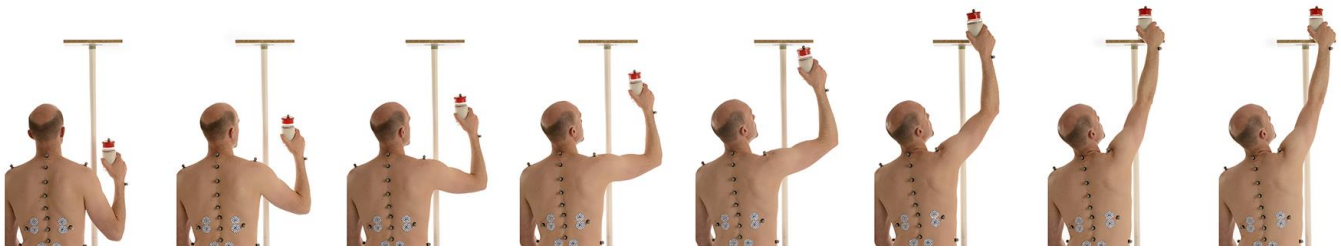


Figure 7: Reach up

Stepping up and down

Subjects were instructed to stand in front of a 6-inch Reebok® step (Reebok®, UK), step onto the step (with a self-selected leading-leg), wait in double-stance on top of the step for 2 seconds, and then step down (with a self-selected leading-leg). The subject was instructed that the self-selected leading-leg must remain consistent throughout trials. To ensure data could be analysed effectively in the MATLAB programme the subject was required to wait in their usual standing position following the step down for 2 seconds to enable the end task position to be defined.

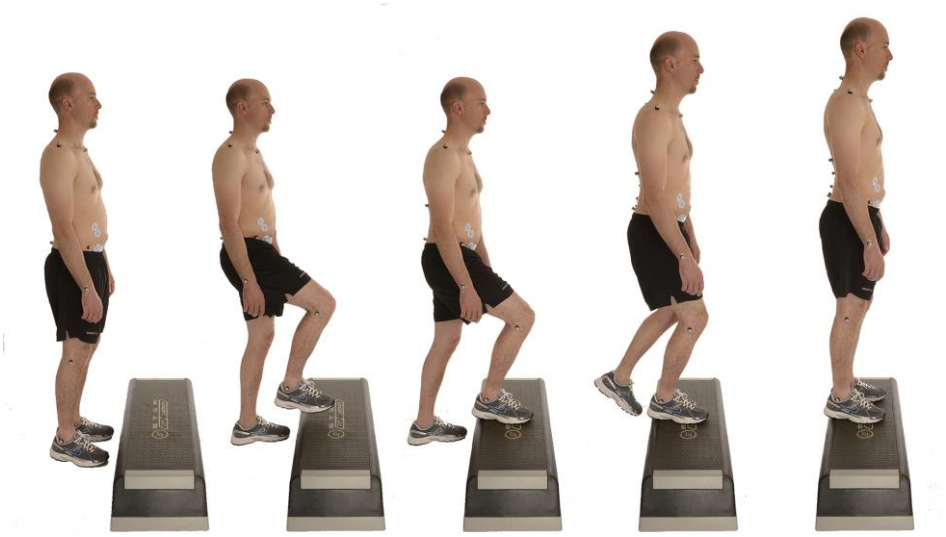


Figure 8: Step up

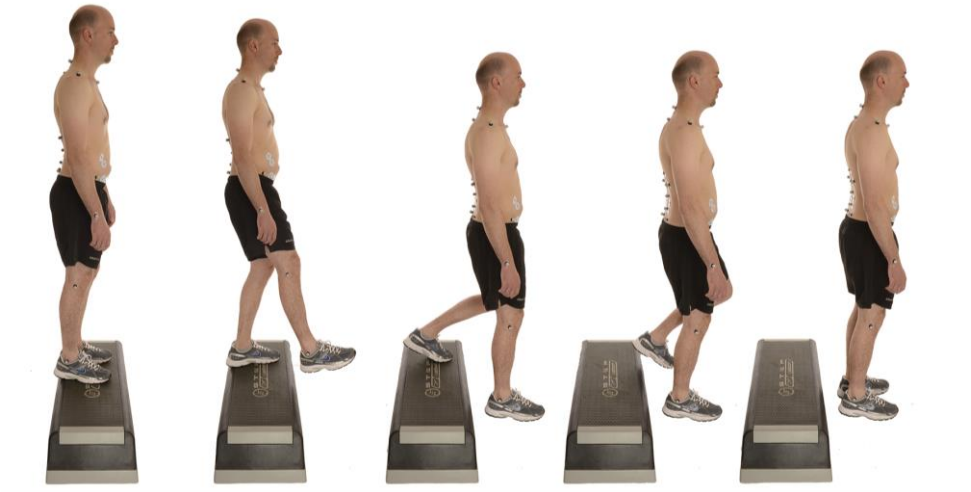


Figure 9: Step down

Bending to pick up a pen (and return)

Subjects stood in their usual standing position with a pen (with a marker attached) placed at a point 40cm in front of them on the floor. Subjects were instructed to pick up the pen from the floor and return to their usual standing position. Subjects were encouraged to pick up the pen in whichever way they felt was most natural ‘as if they had just dropped their own pen and needed to retrieve it’ (Mitchell et al. 2008), however they were instructed to keep their feet stationary throughout the task. Subjects were asked to pick up the pen with their right hand to standardise the movement between subjects.

Figure 10: Bending to pick up a pen (and return)

5.4.2 Data Processing

Data processing was conducted in Vicon Nexus (Nexus 1.8.2 Vicon Motion Systems, Oxford, UK). Data was visually inspected and markers manually labelled using a custom developed marker file. Any gaps in the marker data were manually filled, ghost markers removed and the trials run through a custom developed pipeline (Cardiff University, UK). A virtual S2 marker was created in the Vicon Bodybuilder pipeline and defined as the point exactly halfway between the PSIS markers. 'L3' was defined as the midpoint between the L2 and L4 markers, calculated using a spline interpolation in MATLAB. For trials with sustained trunk flexion movements where ASIS markers were occasionally not visible for prolonged periods and approximate ASIS marker positions were calculated (using data obtained from the PSIS and iliac crest markers during a calibration trial) within the custom-developed pipeline to fill gaps. Data processing was conducted primarily by the lead researcher and a research assistant trained in Vicon data processing. Each trial was exported as a c3d file and run through a custom developed analysis programme in MATLAB (version R2013a, The Mathworks Inc., Natwick, MA, USA) developed by Prof. R.W. van Deursen (School of Healthcare Sciences, Cardiff University, UK).

The custom developed MATLAB programme plotted sagittal spinal angles for the following parameters:

- Total Thoracic Spine (TotTx) – defined as the sum of the angular changes between all of the markers in the C7-T12 region (difference between 'C7 and T2' + 'T2 and T4' + 'T4 and T6' + 'T6 and T8' + 'T8 and T10' + 'T10 and T12')
- Total Lumbar Spine (TotLx) – defined as the sum of the angular changes between all of the markers in the T12-VS2 region (difference between 'T12 and L2' + 'L2 and L3' + 'L3 and L4' + 'L4 and VS2')
- Upper Thoracic Spine (UTx) – defined as the sum of the angular changes between all of the markers in the C7-T6 region (difference between 'C7 and T2' + 'T2 and T4' + 'T4 and T6')
- Lower Thoracic Spine (LTx) – defined as the sum of the angular changes between all of the markers in the T6-T12 region (difference between 'T6 and T8' + 'T8 and T10' + 'T10 and T12')
- Upper Lumbar Spine (ULx) – defined as the sum of the angular changes between all of the markers in the T12-L3 region (NB: L3 defined as above) (difference between 'T12 and L2' + 'L2 and L3')
- Lower Lumbar Spine (LLx) – defined as the sum of the angular changes between all of the ,markers in the L3-VS2 region (difference between 'L3 and L4' + 'L4 and VS2')

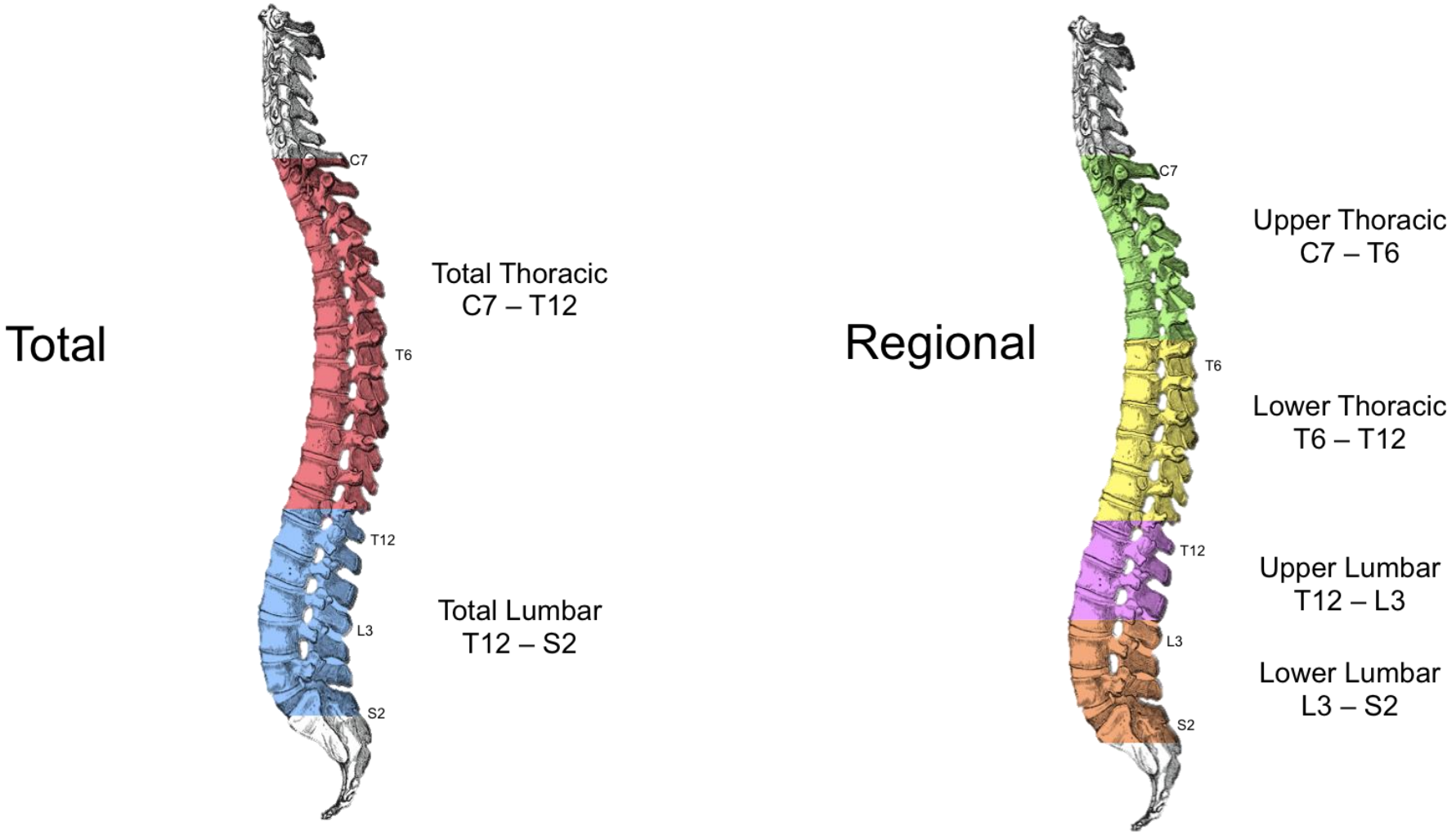


Figure 11: Illustration of spinal regions used for analysis

All sagittal spinal angles were reported relative to the pelvis position (calculated from the ASIS' and PSIS' marker positions). Negative scores are indicative of extension (beyond neutral), and positive scored conversely indicative of flexion (beyond neutral). For usual standing and usual sitting data the midpoint value of the sum of the angular changes in each region was calculated from a 200ms time period exactly halfway into the processed trial. The five activities (sit-to-stand-to-sit, box lift rotate and replace, bend to pick up pen, step up and down and reaching) were sub-divided into 9 separate tasks as outlined in Table 6 using the custom developed MATLAB programme (Cardiff University, UK). For each of the 9 tasks the total and regional spinal differences were evaluated as described in Table 6.

Table 6: Table outlining how the original data collection tasks were split for analysis

Sit-to-stand-to-sit	Sit-to-Stand
	Stand-to-Sit
Box lift, rotate and replace	Box Lift
	Box Replace
Bend to pick up pen	Pen Pick Up (Bend Down)
	Pen Pick Up (Return)
Step up and down	Step Up
	Step Down
Reaching	Reach Up
	Reach Down (NB: not included in analysis)

For each spinal region during each functional task the following parameters were reported:

- Maximum flexion sagittal spinal angle during the movement
- Maximum extension sagittal spinal angle during the movement

The midpoint sagittal spinal angle was calculated as:

$$\frac{\text{Maximum flexion sagittal spinal angle + Maximum extension sagittal spinal angle}}{2}$$

Each c3d file was run through a customised MATLAB programme to obtain the data for these parameters. Graphs were automatically generated in MATLAB for the sagittal spinal angle of each spinal region (UTx, LTx, ULx, LLx, TotTx, TotLx) as a tool to visually check the data. Where any

anomalies in the data were identified the raw data was visually checked, re-processed in Vicon® and re-run through MATLAB to ensure that no errors in the data were attributable to errors in human processing. A custom developed MATLAB collate programme subsequently exported the data as an excel file. The final excel file was imported into SPSS version 20.0 (IBM Corp, 2011 IBM SPSS Statistics for Windows, Armonk, NY) for statistical analysis where a final visual check of the data in graphical form was completed.

5.4.3 Statistical Analysis

Intra-class correlation co-efficients (ICC) with 95% confidence intervals (CI) and the standard errors of the mean (SEM) were calculated in SPSS (version 20.0 IBM Corp, 2011 IBM SPSS Statistics for Windows, Armonk, NY) for the midpoint regional sagittal spinal angles across the 4 trials for each task (within-day reliability) and the overall midpoint regional sagittal spinal angle, averaged across 4 trials for each session (between-day reliability).

Within-subject reliability was assessed using a two-way mixed model (single measures) with consistency (Shrout and Fleiss 1979). In order to determine within-subject variation typical SEM between the four sets of measurements was obtained by calculation of the square root of the "mean squared error", which is reported as an output of the one-way ANOVA (Batterham and George 2003; Hopkins 2000; Stratford and Goldsmith 1997). 95% Confidence intervals were also reported. For between-day (test re-test) reliability a two-way mixed model (average measures) with consistency was used (Shrout and Fleiss 1979) and SEM obtained (method as described previously). 95% confidence intervals for between-day reliability were calculated by determining the numerical difference between the mean measure obtained from session 1 and session 2 (average of 4 trials) (Hopkins 2000).

To interpret the relevance of the ICC 'reliability' level an ICC score of > 0.80 was considered 'excellent', > 0.61–0.80 'substantial', 0.40–0.60 'moderate' and < 0.40 'slight' (Landis and Koch 1977). This framework is consistent with other reliability studies reporting reliability of spinal posture measurement (O'Sullivan et al. 2011; Sheeran et al. 2010).

5.5 Results

5.5.1 Subject Demographics

Five males (34.2 ± 6.4 years; height 173.5 ± 13.9 cm; mass 82.4 ± 23.6 kg; BMI 27.2 ± 6.2 kg/m²) and 5 females (37.8 ± 15.7 years; height 166.5 ± 8.0 cm; mass 65.5 ± 7.0 kg; BMI 23.6 ± 1.2 kg/m²) participated in the study (Table 7).

An independent samples t-test revealed no significant differences in BMI between the participants based on gender (p= 0.239) with BMI values for both males and females appearing to generally lie within healthy weight limits (18.5 – 24.9 kg/m^2) (National Institute for Health and Clinical Excellence. 2015).

Table 7: Subject demographics

	Mean	**Standard Deviation**	**Range (min-max)**
Age (years)	36	11.5	21 - 60
Height (cm)	170.0	18.7	151.0 – 188.0
Mass (kg)	73.9	18.7	59.4 – 119.8
BMI (kg/m^2)	25.4	4.6	21.6 – 37.8

Key: cm = centimetres, kg = kilogrammes, kg/m^2 = mass in kilogrammes divided by height in meters squared

5.5.2 Within-Subject Reliability

Table 8: Within-subject reliability results for midpoint regional sagittal spinal angle during the functional tasks

		Total Thoracic	Total Lumbar	Upper Thoracic	Lower Thoracic	Upper Lumbar	Lower Lumbar
Step Down	ICC (95% CI)	0.829 (0.627 to 0.947)	0.951 (0.878 to 0.986)	0.925 (0.820 to 0.978)	0.934 (0.840 to 0.981)	0.908 (0.782 to 0.973)	0.879 (0.723 to 0.964)
	SEM	2.5	3.4	1.75	1.7	2.7	5.8
	Cronbachs Alpha	0.951	0.987	0.98	0.983	0.975	0.967
Step Up	ICC (95% CI)	0.779 (0.542 to 0.930)	0.952 (0.881 to 0.986)	0.882 (0.728 to 0.965)	0.903 (0.771 to 0.971)	0.892 (0.748 to 0.968)	0.875 (0.715 to 0.963)
	SEM	2.8	3	2	2.1	2.8	5.5
	Cronbachs Alpha	0.934	0.988	0.968	0.974	0.97	0.966
Reach Up	ICC (95% CI)	0.914 (0.795 to 0.975)	0.925 (0.820 to 0.978)	0.968 (0.920 to 0.991)	0.955 (0.888 to 0.987)	0.925 (0.819 to 0.978)	0.963 (0.908 to 0.990)
	SEM	2.2	4	1.5	1.6	2.2	3.4
	Cronbachs Alpha	0.977	0.98	0.992	0.988	0.98	0.991
Pick up Pen (Return)	ICC (95% CI)	0.895 (0.755 to 0.969)	0.960 (0.899 to 0.988)	0.907 (0.781 to 0.973)	0.928 (0.827 to 0.979)	0.877 (0.718 to 0.963)	0.879 (0.722 to 0.964)
	SEM	2.8	2.4	2	1.9	2.3	4.6
	Cronbachs Alpha	0.971	0.99	0.975	0.981	0.966	0.967
Pick up Pen (Bend)	ICC (95% CI)	0.873 (0.711 to 0.962)	0.945 (0.864 to 0.984)	0.874 (0.712 to 0.962)	0.888 (0.740 to 0.967)	0.849 (0.665 to 0.954)	0.876 (0.718 to 0.963)
	SEM	2.9	2.7	2.2	2	2.6	5.5
	Cronbachs Alpha	0.965	0.986	0.965	0.969	0.957	0.966
Box Replace	ICC (95% CI)	0.881 (0.726 to 0.964)	0.952 (0.880 to 0.986)	0.919 (0.806 to 0.976)	0.938 (0.848 to 0.982)	0.914 (0.795 to 0.975)	0.965 (0.911 to 0.990)
	SEM	2.4	3.4	2.1	2.1	2.6	2.9
	Cronbachs Alpha	0.967	0.987	0.978	0.984	0.977	0.991
Box Lift	ICC (95% CI)	0.810 (0.595 to 0.855)	0.927 (0.823 to 0.979)	0.888 (0.742 to 0.967)	0.923 (0.816 to 0.978)	0.919 (0.807 to 0.977)	0.943 (0.861 to 0.984)
	SEM	3.4	3.7	2.5	2	2.4	3.8
	Cronbachs Alpha	0.945	0.981	0.97	0.98	0.979	0.985
Sit-to-Stand	ICC (95% CI)	0.886 (0.738 to 0.966)	0.959 (0.898 to 0.988)	0.930 (0.831 to 0.980)	0.936 (0.845 to 0.982)	0.844 (0.655 to 0.952)	0.835 (0.640 to 0.950)
	SEM	2.7	2.7	2.4	1.9	3	4.6
	Cronbachs Alpha	0.969	0.99	0.982	0.983	0.956	0.953
Stand-to-Sit	ICC (95% CI)	0.746 (0.490 to 0.918)	0.977 (0.941 to 0.993)	0.933 (0.836 to 0.981)	0.963 (0.907 to 0.989)	0.862 (0.690 to 0.958)	0.820 (0.612 to 0.944)
	SEM	3.4	2.3	2	1.4	3.2	5.4
	Cronbachs Alpha	0.921	0.994	0.982	0.99	0.962	0.948

Key: ICC = Interclass Correlation Coefficient, CI = Confidence Interval, SEM = Standard Error of Measurement (degrees)

Within-subject reliability scores are reported in Table 8. Overall ICC values demonstrated substantial to excellent reliability with ICC scores of 0.746 to 0.977 across all spinal regions and tasks. Mean score ICCs ranged from 0.746 (95% CI 0.490 to 0.918) in the total thoracic spine during the stand-to-sit task, to 0.977 (95% CI 0.941 to 0.993) in the lower lumbar region during stand-to-sit task across the 4 trials. Typical error for the within-subject results ranged from 1.4 degrees in the lower thoracic region during stand-to-sit to 5.8 degrees in the total lumbar spine during the reach up task. The Cronbach's Alpha coefficient for each item is >0.92, suggesting that there is high internal consistency. Overall, over 96% of the ICC results for the within-subject reliability scores were >0.80 indicating excellent reliability (Landis and Koch 1977).

5.5.3 Between-Day Reliability

Table 9: Between-day reliability results for midpoint regional sagittal spinal angle during the functional tasks

		Total Thoracic	Total Lumbar	Upper Thoracic	Lower Thoracic	Upper Lumbar	Lower Lumbar
Step Down	ICC (95% CI)	0.787 (0.143 to 0.900)	0.935 (0.585 to 0.968)	0.958 (0.831 to 0.990)	0.848 (0.386 to 0.962)	0.874 (0.495 to 0.969)	0.756 (0.020 to 0.940)
	SEM	4.6	4.8	1.8	3.2	3.7	7.9
Step Up	ICC (95% CI)	0.762 (0.043 to 0.941)	0.954 (0.686 to 0.977)	0.938 (0.748 to 0.984)	0.849 (0.391 to 0.962)	0.865 (0.458 to 0.967)	0.734 (-0.073 to 0.934)
	SEM	4.7	3.8	2.2	3.1	3.7	7.6
Reach Up	ICC (95% CI)	0.949 (0.795 to 0.987)	0.927 (0.707 to 0.982)	0.964 (0.854 to 0.991)	0.817 (0.263 to 0.955)	0.800 (0.195 to 0.950)	0.777 (0.103 to 0.945)
	SEM	2.4	4.7	2.1	3.5	4.3	8.6
Pick up Pen (Return)	ICC (95% CI)	0.936 (0.744 to 0.984)	0.949 (0.793 to 0.987)	0.940 (0.758 to 0.985)	0.750 (-0.005 to 0.938)	0.934 (0.736 to 0.984)	0.873 (0.487 to 0.968)
	SEM	2.8	3.3	2.3	3.9	2.2	4.9
Pick up Pen (Bend)	ICC (95% CI)	0.933 (0.576 to 0.967)	0.955 (0.817 to 0.989)	0.896 (0.580 to 0.974)	0.618 (-0.537 to 0.905)	0.940 (0.760 to 0.985)	0.803 (0.209 to 0.951)
	SEM	2.4	3.1	2.6	3.9	2.1	6.8
Box Replace	ICC (95% CI)	0.950 (0.665 to 0.975)	0.870 (0.478 to 0.968)	0.949 (0.793 to 0.987)	0.853 (0.410 to 0.964)	0.856 (0.422 to 0.964)	0.744 (-0.031 to 0.936)
	SEM	2.2	6.2	2.4	3.7	3.8	7.8
Box Lift	ICC (95% CI)	0.921 (0.682 to 0.980)	0.923 (0.691 to 0.981)	0.887 (0.545 to 0.972)	0.859 (0.432 to 0.965)	0.849 (0.391 to 0.962)	0.816 (0.261 to 0.954)
	SEM	2.9	4.5	3.5	3.3	3.9	7
Sit-to-Stand	ICC (95% CI)	0.947 (0.786 to 0.987)	0.977 (0.908 to 0.994)	0.876 (0.499 to 0.969)	0.881 (0.522 to 0.971)	0.946 (0.783 to 0.987)	0.917 (0.667 to 0.979)
	SEM	2.6	2.7	3.9	3.6	2.1	4
Stand-to-Sit	ICC (95% CI)	0.894 (0.572 to 0.974)	0.978 (0.913 to 0.995)	0.857 (0.425 to 0.965)	0.843 (0.367 to 0.961)	0.950 (0.800 to 0.988)	0.925 (0.697 to 0.981)
	SEM	3.3	2.9	3.9	4	2.3	4.1

Key: ICC = Interclass Correlation Coefficient, CI = Confidence Interval, SEM = Standard Error of Measurement (degrees)

Between-day reliability scores are reported in

Table 9. Overall ICC values demonstrated substantial to excellent reliability with ICC scores of 0.618 to 0.978 across all spinal regions and tasks. ICCs ranged from 0.618 (95% CI -0.537 to 0.905) in the lower thoracic spine during the pick up pen (bend) task, to 0.978 (95% CI 0.913 to 0.995) in the total lumbar region during the stand-to-sit task between the 2 sessions. Typical error for the within-subject results ranged from 1.8 degrees in the upper thoracic region during the step down task to 8.6 degrees in the lower lumbar spine during the reach up task. Overall, over 85% of the ICC results for the between-day reliability scores were >0.80 indicating excellent reliability (Landis and Koch 1977).

5.6 Discussion

The primary objective of this study was to evaluate the within-subject and between-day consistency and variability of spinal movement using a novel spinal marker set during repeated functional movements in healthy subjects. The results show substantial to excellent reliability of the marker set to report movement consistently across continuous trials (within-subject) (ICC 0.746 to 0.977), which is replicable when re-tested across two sessions (ICC 0.618 to 0.978) using this marker set and methodological framework.

Within-subject typical error did not exceed 5.8°, however between-day error was higher at 8.6° with a greater overall range (1.8° to 8.6°). This increased overall SEM for between-day reliability suggests the between-day results in this small sample size should be considered cautiously for evaluation in the lumbar spine region and could be due to manual marker placement error by the tester. It may also be attributable to variation in movement strategies adopted by the individual. However the ICC values between-day were observed to be comparable with other approaches to spinal measurement (0.618 to 0.978), including radiographical methods (Pinel-Giroux et al. 2006), the Spinal Mouse® (Mannion et al. 2004) and the spinal wheel (Sheeran et al. 2010) . With regard to poor between-day SEM scores no trends were observed with regard to one specific spinal region or task, indicating that lower error measurement may be attributable to the small sample size.

Within-subject ICC results suggest the marker set appears to consistently record regional spinal angles during repeated testing of functional tasks. Another factor for consideration is reduced variability of healthy human movement during these functional tasks. Variability of repeated human spinal movement is difficult to quantify due to difficulty in dissociating measurement error from true movement variability. These preliminary results suggest however, that the marker set is potentially a robust and accurate approach to spinal measurement during functional tasks. Thus it could tenuously be hypothesized that healthy individuals operate in a similar spinal ROM through repeated tasks.

Between-day reliability can be influenced by static offsets caused by slight alterations in marker application (Growney et al. 1997; Kadaba et al. 1989). Kadaba et al. (1989) and Della Croce et al. (2005) suggest that even slight differences in anatomical landmark marker placement in 3D motion analysis can result in incorrectly defined segment co-ordinate system axes, leading to incorrect joint rotations (Chockalingam et al. 2005). The substantial to excellent between-day ICC scores indicate that this novel marker set and methodological approach appears to minimize the influence of static offsets. It is acknowledged that the marker set cannot provide a true replication of bony vertebral movement due to skin movement artefact and adipose tissue overlying the bony structures, however

with the increased number of retro-reflective markers (especially in the thoracic spinal regions), and subsequent increased inter-segmental angle calculation, it appears that the marker set is able to consistently record overall spinal movement patterns. Additionally, the small surface area of the spinous processes, as the primary bony anatomical landmarks for marker placement, could be argued to be easier to locate for reapplication of markers between sessions. Della Croce et al. (2005) suggest the greater the irregularity and size (or surface area) of an anatomical bony landmark, the greater the potential for marker placement error.

The consistency of the tester is another factor directly affecting replicability of marker placement and subsequent static offsets. A chartered physiotherapist (4 years post-qualification) with experience of palpation of anatomical bony landmarks and a specialist interest in the spine conducted all data collection and preparatory procedures. Previous experience of using 3D motion analysis has not been found to be a factor with regard to the accuracy of marker placement when compared to a physiotherapist with no previous 3D motion analysis experience (Leigh et al. 2014). It appears that it may be of greater importance for replicability of marker application for the tester to be more familiar with anatomy and palpation of bony landmarks rather than understanding the data collection system.

To counteract the influence of human marker placement error some studies have developed marker placement devices (MPD) to more accurately replicate marker placement between sessions (Noehren et al. 2010; Telfer et al. 2010). The devices which can store 3D co-ordinates of manually placed markers to replicate on a repeated session have been shown to significantly increase the between-day reliability of sagittal peak angles in the ankle and hip by 10% compared to manual marker placement (Noehren et al. 2010). The results of this study however suggest manual marker placement using this marker set to be sufficiently able to replicate spinal movement patterns between sessions.

The findings of this study are in agreement with previously published literature on measurement of spinal posture and global and segmental ROM of the spine during spinal flexion and extension using the spinal mouse® (a wheeled accelerometer device) (Mannion et al. 2004). Between-day reliability of the device was evaluated with two testers to evaluate total thoracic and total lumbar spinal angle. Consistent with between-day results obtained in the current study, between-day ICCs ranged from 0.67-0.88 and 0.78-0.92 (SEM values 2.8-6.2° and 2.4-5.1°) for the thoracic and lumbar spine regions respectively, demonstrating the methodological approach to be comparable with the spinal mouse®. A further advantage of the spinal marker set is the ability to further discriminate the spine into sub-divided spinal regions (upper and lower thoracic and lumbar) (Mitchell et al. 2008).

With obesity becoming an increasing worldwide phenomenon (Wang et al. 2011) contributing to many musculoskeletal conditions, measurement tools must be able to accurately evaluate kinematics

in this subject group (Lerner et al. 2014). Adipose tissue and skin movement artefact are cited as sources of potential error for marker placement and accuracy (Hart and Rose 1986; Peters et al. 2010) with increased soft tissue thickness identified to be associated with reduced accuracy of palpation and identification of spinous processes (Harlick et al. 2007). In the current study BMI ranged from 27.2 ± 6.2. Although the BMI values generally fell within an acceptable range with 60% of subjects classed as 'healthy' (BMI 21-25), the average BMI score of 27.2 is classified as overweight. On closer inspection, 9 (out of 10) subjects had a BMI less than 27 and one subject had a BMI of 37.8 (classified as obese), which will skew the overall mean value. Despite this excessive BMI, and the established impact of BMI and adipose tissue as a source of marker error, the study findings appear to indicate that BMI has little overall impact on recorded spinal movement patterns and angle. The preliminary results presented here suggest that to an extent the marker set is able to consistently record spinal patterns in larger subjects, however without radiological comparison it is not possible to evaluate how closely reported angles reflect true vertebral movement in either the healthy, overweight or obese subjects.

5.6.1 Limitations

This preliminary study was undertaken on a relatively small sample size (n=10). Hopkins (2000) state that approximately 50 subjects are required for greater precision in reliability research, thus the findings must be regarded as preliminary and the results interpreted cautiously. Due to the time required for data processing of 3D motion analysis data, a larger subject sample obtained via an additional data collection session was not feasible within the time constraints of the PhD project. However, in the main study results (Chapter 7) further within-subject reliability is explored across the three repeated trials for the healthy group (n=28), and sub-grouped NSCLBP subjects (n=50 (27 FP-MCI, 23 AEP-MCI)). A larger and more diverse (e.g. greater age range, BMI) sample may have provided greater clarity with regard to the within-subject and between-day reliability for the use of this marker set in the wider population and for use in symptomatic cohorts. However the preliminary results from this study are encouraging and support the use of this marker set as a robust approach to the measurement of functional movement in the spine.

There is a small possibility of a learning effect occurring between sessions as subjects are consciously aware within the data collection sessions that their position and posture is being monitored and subsequently may potentially alter their natural postural movement strategies between sessions, or even on repeated trials. However, the results appear to negate this theory, with subjects producing highly consistent results in all spinal regions within sessions and between days. The number of days

between sessions in this study varied greatly (minimum of 7) also reduces any potential carry-over or learning effect.

The data reported here was collected as part of a larger study (Chapter 6). During the initial data collection session the subject also underwent sEMG recording with multiple skin electrodes placed over anterior and posterior trunk musculature. Subjects were also required to wear a belt with an EMG signal box over the left anterior hip. Electrodes and EMG wires could be argued to impact upon subjects' ability to perform functional tasks consistently when compared with the second session where no electrodes or wires were attached. Although this is a limitation of the methodology, the between-day results suggest that the presence of the electrodes and leads had little effect on the consistency of the task performance.

Directions for future research could include evaluation of within-day reliability of the marker set, however given the study findings it is anticipated that re-application of the markers and re-testing undertaken on the same-day would yield similar results to that of the between-day reliability scores for the study. Evaluation of inter-tester reliability to establish whether differences in regional sagittal spinal angle are observed within- and between-days when the marker set is applied by both expert clinicians and biomechanists compared to novice users would establish the methodology for replication in further research trials. Having established substantial to excellent within-subject reliability across repeated tasks in healthy individuals, repeating the study design with symptomatic cohorts, for example NSCLBP subjects could establish whether this consistency of functional movement continues to be observed in these cohorts to gain insight into altered postural adaptions and fear of movement. Within-subject reliability of these subjects, evaluated across 3 repeated trials, with regard to both spinal kinematics and muscle activity, are reported in Chapter 7.

5.7 Conclusion

This study supports the use of this novel marker set to evaluate regional spinal movement during functional activity. The results suggest that this approach can provide a robust biomechanical methodology for comparing spinal movement patterns in healthy subjects during functional activities. This methodology will enable studies to be conducted to investigate maladaptive postural strategies, which may influence the development of chronic pain.

6 METHODS – Main Study

6.1 Study Design

An observational, case-control study design explored differences in spinal kinematics, evaluated using a 3D motion analysis (Vicon®) system, and trunk muscle activation, evaluated using surface electromyography (sEMG), between two subclassified MCI sub-groups of NSCLBP (AEP and FP MCI) and a healthy control group. The primary aim was to identify between group differences in spinal kinematics and muscle activity to provide valuable insight into the movement behaviour of subclassified NSCLBP patient groups compared to healthy individuals.

6.2 Subjects

6.2.1 Recruitment Procedures

NSCLBP patients were sampled from routine physiotherapy waiting lists for 5 Physiotherapy Departments within the Cardiff and Vale University Health Board (Cardiff, UK) between January 2012 and March 2013. The lead researcher visually screened all routine physiotherapy referral forms to identify all potentially eligible patients. Patients identified were sent a covering letter (Appendix IV) along with an Arthritis Research UK Biomechanics and Bioengineering Centre Permission to Contact Form (Appendix IV) and a stamped addressed envelope to return should they wish to be contacted to participate in the study. All subjects who requested to be contacted were phoned by a National Institute for Social Care and Health Research (NISCHR) research officer to explain the study in greater detail, answer any queries and conduct a series of screening questions to establish whether the individual met the inclusion / exclusion criteria (Table 10). All subjects meeting the criteria and wishing to participate in the study were given an appointment to attend a data collection session.

Eighty-five NSCLBP subjects completed the full data collection protocol. Nine data collection sessions were discarded due to poor quality trials. A further 9 subjects were identified, post-data collection, as having a movement impairment (not MCI) following a review of the video-footage and written assessment documentation by the second assessor (Section 6.3.1). The remaining 67 NSCLBP subjects were classified as presenting with MCI (23 AEP, 27 FP, 8 PEP, 9 MDP) (Figure 12). A power calculation for the study was conducted and a sample size calculation of 24 subjects in each group was found to be appropriate to detect between group differences in kinematics in these patient

sub-groups (Section 6.14.2, Appendix VII). Recruitment for the study was stopped in March 2013, once sufficient subjects had been recruited for each group.

Healthy control subjects were recruited from the Cardiff and Vale area (Cardiff, Wales, UK) via advertising posters in Cardiff University buildings, word-of-mouth and the Cardiff University notice board and were Cardiff University staff, students, and friends and relatives of staff who met the inclusion criteria (Table 11). Control subjects were matched for age, BMI and physical activity (IPAQ-SF) as both sedentary lifestyles and excessive physical activity are proposed to be risk factors for low back pain (Heneweer et al. 2009; Hildebrandt et al. 2000). A total of 122 subjects (85 NSCLBP and 37 healthy control) were recruited to the study and participated in the data collection sessions.

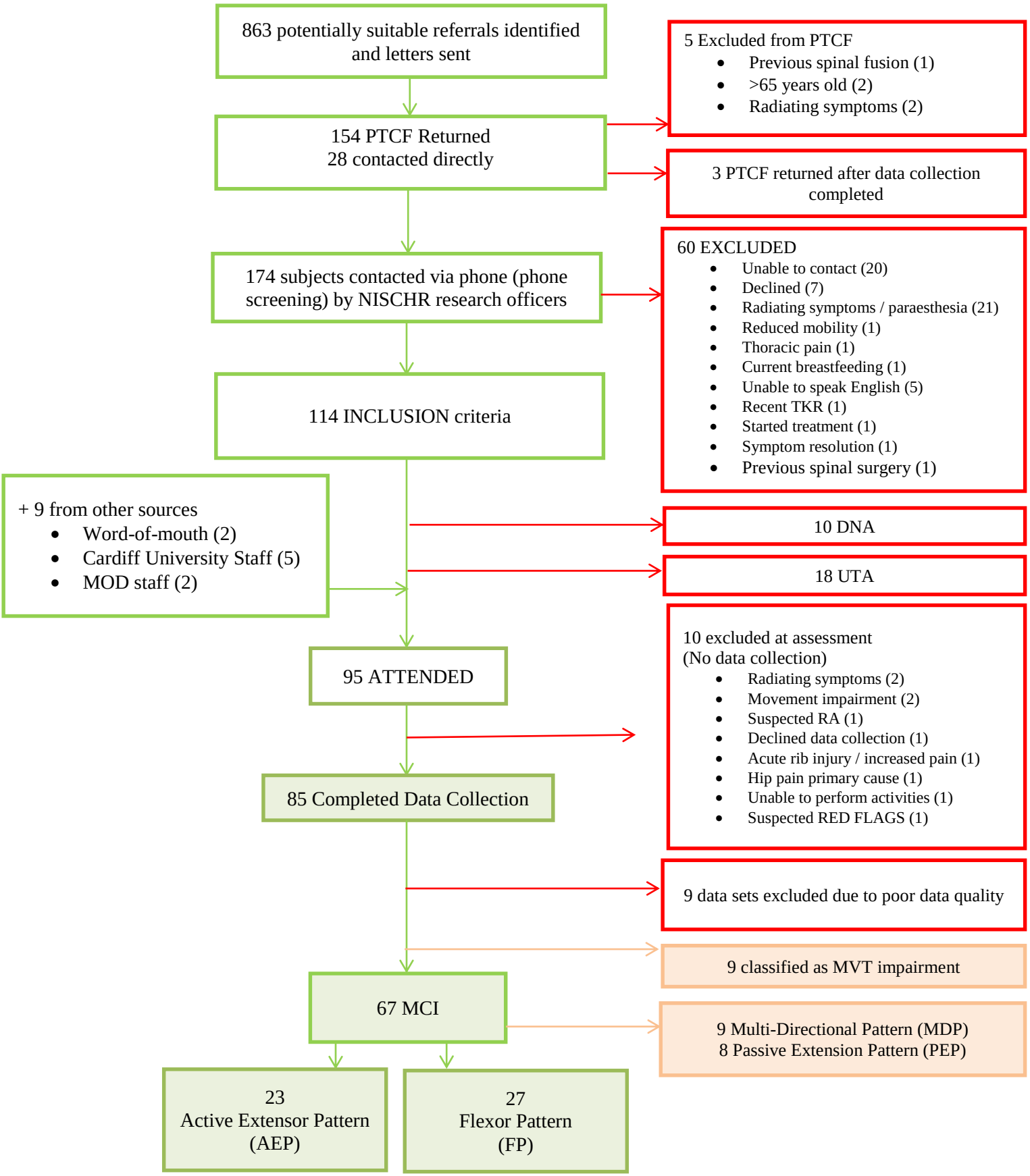


Figure 12: Flowchart of recruitment procedures for NSCLBP subjects

6.3 Inclusion and Exclusion Criteria

Table 10: Inclusion and exclusion criteria for the non-specific chronic low back pain (NSCLBP) group

Inclusion criteria for the NSCLBP group	Exclusion criteria for the NSCLBP group
• Aged 18 -65 years • History of chronic LBP (>12 weeks) • Pain in the lumbar and / or buttock region (defined as pain reported below the level of T12 and no lower than the buttock creases) • Clear mechanical basis of the disorder aligned with specific aggravating and easing postures and movements as described by O'Sullivan (2005), with distinct symptom relief observed during movement conducted in the opposing direction of reported pain provocation (assessed subjectively and objectively) • Clinical diagnosis of specific motor control impairment (MCI) - either flexion pattern (FP) or active extension pattern (AEP) motor control impairment.	• Red flags (including significant trauma, unexplained weight loss and widespread neurologic changes) (Koes et al. 2010; van Tulder et al. 2006; Waddell 2004) (Appendix V) • Any vestibular, visual or neurological dysfunction affecting balance • Current radiating symptoms (and / or neurological deficit) below the level of the buttock crease • Current pregnancy or breastfeeding • History of spinal surgery, fracture or malignancy • Inability to perform any of the functional tasks unaided • Inability to read written English language documents and follow verbal instructions in English • Not fulfilling the inclusion criteria

Strict inclusion and exclusion criteria were applied, based on the MDCS (O'Sullivan 2005) (Table 10). Inclusion criteria was: current low back pain of duration greater than 12 weeks and pain in the lumbar region which did not radiate below the level of the buttock crease. Radiating symptoms can be indicative of underlying neural involvement, such as nerve root compression, and thus a specific underlying cause for pain (Deyo 1986). Participant age was capped at 65 as age related changes such as degenerative lumbar spinal stenosis, have been shown to be increasingly prevalent in people aged 65 and over (Kalff et al. 2013). This age range is also consistent with other epidemiological literature exploring CLBP populations (Andersson 1999; Nagi et al. 1973), as well as studies investigating between group differences in these MCI sub-group patient cohorts (Dankaerts et al. 2006a, c; Sheeran et al. 2012).

In order to fulfil the MDCS criteria a clear mechanical basis for the disorder must be established where specific aggravating and easing postures and movements are aligned with clinical assessment criteria (O'Sullivan 2005) as implemented in other studies (Dankaerts et al. 2006a, c; Fersum et al. 2013; Sheeran et al. 2012). A full detailed outline of the MDCS is provided in section 2.3.3. AEP and FP patterns appear to be the most prevalent patterns observed clinically and have thus far been the primary MCI sub-groups investigated due to logistics and convenience of sampling (Dankaerts and O'Sullivan 2011). Due to the sample size power calculation of approximately 24 subjects in each group (section 6.14.2), only the results of the AEP and FP subjects reached this threshold within the time period allocated for data collection, thus the results reported are limited to these groups and a healthy control group.

Any current vestibular dysfunction, visual disturbance (e.g. double vision, blindness) or previous neurological dysfunction which may have influenced activity performance was considered exclusion criteria due to the potential affect on balance for health and safety reasons. Females who were breastfeeding or pregnant were also excluded from the study due to physiological adaptations and temporary biomechanical alterations to spinal posture which could skew the data.

Any patients displaying red flags (Koes et al. 2010; van Tulder et al. 2006; Waddell 2004) (Appendix V) were immediately referred for further investigation and were not suitable for the study. Although yellow flags are considered separately to NSCLBP in the MDCS, little is currently known as to whether this patient group still exhibit similar deficits in motor control compared to patients who do not express a pre-dominance in these behaviours. For this study patients who presented clinically with either AEP or FP MCI but who scored above 37 on the TSK (Miller et al. 1991; Vlaeyen et al. 1995) and DRAM (Main et al. 1992), were still included within the study. However, this data can be used in future to evaluate the potential impact of increased fear of movement (fear avoidance) and distress levels on spinal kinematics and muscle activity in MCI subgrouped patients.

Table 11: Inclusion and exclusion criteria for the healthy control group

Inclusion criteria for the healthy control group	Exclusion criteria for the healthy control group
• Aged 18 – 65 years	• History of LBP or any lower limb pain in the last 2 years • Any vestibular, visual or neurological dysfunction affecting balance • Pregnancy / Breastfeeding • History of spinal surgery, fracture or malignancy • Previous LBP with symptoms radiating below the level of the buttocks • Inability to complete the tasks required • Inability to read written English language documents and follow verbal instructions in English

The inclusion criterion for the healthy control group was adults aged between 18-65 years, to act as age matched controls for the NSCLBP sub-groups. Any history of LBP or any lower limb pain in the past 2 years was classed as exclusion criteria, as these subjects may have pre-existing maladaptive motor control strategies which may be a confounding factor when comparing with symptomatic back pain cohorts. If the participant had a history of LBP more than 2 years previously but had been asymptomatic during the past 2 years, it was considered appropriate to assume that 'normal' pain-free movement was consistently achieved, and the subject was included as a healthy control. This approach has been utilised in previous similar studies (Dankaerts et al. 2006a, c). Conversely, subjects with any history of previous LBP with symptoms radiating below the level of the buttocks were deemed to have potentially experienced previous specific underlying structural changes, and were therefore excluded.

6.3.1 MCI classification

Due to financial and time constraints of the study the lead investigator (RH), a chartered physiotherapist with 4 years clinical experience, who had received specialist training in the MDCS prior to data collection, performed all subjective and objective assessments. For the subjective assessment subjects were asked to describe: the history of their present condition including symptom

onset and duration of symptoms; the area of their pain and pain behaviour (e.g. 24 hour pattern of pain, pain description); specific aggravating and easing factors (to establish potential directional bias); and any relevant co-morbidities or past medical history. Hobbies and occupations were also disclosed and explored in greater detail if potentially relevant to the subjects reported pain provocation.

A battery of postures, spinal ROM and functional movements were visually observed and video recorded for the objective assessment, to enable a second assessor (LS) to independently review the MCI classifications at a later date. The postures and movements evaluated included usual standing, trunk flexion, trunk extension, lateral side flexion (bilaterally), usual sitting, sitting-to-standing-to-sitting and single leg stance (bilaterally). Movements were recorded via video camera in both the sagittal and frontal plane to ensure the second assessor would have sufficient visual data to accurately apply the MDCS. Additionally, throughout the objective assessment the subject was asked to describe and identify the area and behaviour of pain. PPIVMS (Passive Physiological Intervertebral Movements) (Maitland et al. 2013) were also performed (with the patient positioned in side lying on a treatment plinth) at, above, and below the level of the pain provoking spinal segment to assess the presence of joint hypo- or hypermobility. If hypomobility is observed into the painful spinal segment this supports the rationale for movement impairment, not MCI, and can therefore be used as a differentiation tool (O'Sullivan 2005).

The subjective assessment, video-recorded objective assessment, and PPIVM assessment were reviewed by the second assessor (LS), a senior physiotherapist / researcher trained in the classification approach and who has previously published work in this area, to subclassify the subjects. Following the second assessor's classification decision, both assessors met and discussed in detail each subject's classification to reach a unanimous decision. If a definitive final classification could not be agreed the subject's data was omitted from the final data analysis. In the absence of an opportunity to blind the lead researcher to the subjects' classification group, this approach was utilised to reduce the influence of bias by the lead researcher. Previous research has identified that clinicians have good inter-rater reliability in applying the subclassification system, consistently achieving the same classifications as experts in the approach, once appropriate training in the MDCS has been undertaken (Dankaerts et al. 2006d; Fersum et al. 2009). The lead researcher, although trained in the approach was a novice user of the MDCS and therefore, classification via a highly experienced clinician with a high level of expertise in using the approach was used to increase the robustness of the study.

6.4 Ethical Considerations

Ethical approval for the study was obtained from The Research Ethics Committee 3 Wales (10/MRE09/28) as part of the Arthritis Research UK Biomechanics and Bioengineering Centre, Cardiff University. All photographs involving human subjects included in this thesis are reproduced with the written permission of the individual.

6.4.1 Recruitment

An honorary research contract was obtained from Cardiff and Vale University Health Board for the principal researcher. This contract allowed the principal researcher to access patient referrals for the purpose of patient recruitment. Each invited participant received Arthritis Research UK information sheets regarding the study (Appendix IV) to ensure they were aware of why they were being contacted and informed regarding the study protocol. All patients were offered the opportunity to contact the researcher directly (via email or phone) to discuss the project in detail before deciding to return the PTCF (as indicated in the covering letter). Patients who returned the PTCF and were found to be eligible following the phone call screening were allocated an appointment time over the phone and sent formal written confirmation of the session booking alongside a map and directions for the study location. Email and text confirmation of booking was also offered. A similar procedure was followed for healthy control subjects, however subjects contacted the researcher directly (from posters, word-of-mouth or contact details on the university notice board). Booking confirmation and information sheets for the study were emailed (Appendix IV), or sent via post at the subject's request.

All NSCLBP subjects contacted were currently on routine waiting lists for physiotherapy (waiting list time approximately 16 weeks at the time of the study) and had not commenced physiotherapy treatment at the time of data collection, to eliminate any potential influence of the study on their physiotherapy intervention, and conversely the impact of physiotherapy intervention on the data collected in the study. Subjects were informed that participating in the study in no way influenced their position on the physiotherapy waiting list. Participants were notified on multiple occasions, including via the covering letter and during the phone call screening and data collection session, that the study was observational and that no treatment would be conducted, however following data collection all patients were provided with a standardised gentle exercise sheet (Appendix V) and a copy of 'The Back Book' (Burton et al. 2002) a peer-reviewed back pain booklet, to assist with self-management of pain.

6.4.2 Data Collection

Full informed consent was obtained on the subject's arrival at the data collection session. The study protocol was described to the patient in full by the researcher, with participants given the opportunity to ask questions. Subsequently the participant completed and signed a consent form (Appendix IV) and was informed of their right to withdraw from the study at any time.

Subjects were required to wear shorts, comfortable flat shoes and bras (women) throughout the session. During data collection all female participants were offered a backless vest-top to wear to maintain modesty whilst allowing the markers to remain visible. Changing facilities and privacy curtains were provided and the laboratory door was closed to prevent disruption during data collection. Palpation of anatomical bony landmarks (including the spine and pelvis) was required to accurately affix the reflective markers. Full informed verbal consent was gained prior to palpation to ensure the subject felt comfortable at all times.

6.4.3 Data Storage and Handling

All video-data was filmed such that subjects were unable to be identified from the videos. Videos were recorded using a high-definition (HD) camcorder (Canon Legria HF R606, Canon, Surrey, UK) and stored on a secure digital (SD) high capacity memory card, before being transferred onto an encrypted hard drive. All data held on the memory card was deleted following data collection. All video-footage and data collected was assigned an anonymised code and stored on an encrypted hard-drive. All electronic patient identifiable data was stored on a password protected encrypted hard drive. Permission to contact forms and written information (e.g. demographics, questionnaires) collected at the data collection session were stored in a locked filing cupboard in a secure room within the university accessible only by the researcher and NISCHR research officers. Anonymised codes for each subject were used throughout, with the database linking session codes with specific subjects stored on encrypted password protected devices to ensure subjects were non-identifiable. No concurrent video data was collected within the Vicon® system, therefore the subject was non-identifiable from the 3D motion analysis and electromyography data within Vicon® (e.g. for raw data viewing, processing and analysis).

6.4.4 Dissemination

The intellectual property of this study is held by Cardiff University. The study results will be published in a peer-review journal and all participants will be notified of the journal reference when

published. All peer-reviewed journal articles will be published as Open Access resources to comply with Cardiff University and Arthritis Research UK guidelines.

6.4.5 Risk Assessment

A full risk assessment (Cardiff University: http://www.cardiff.ac.uk/osheu/toolkit/raindex.html) was performed prior to data collection. Due to the repetition of movements required during data collection, patients were fully informed about the protocol procedures prior to commencing the activities and warned about potential pain provocation, for example through repeated bending movements. Pain was monitored using a verbally reported pain score (0-10: 0 = "no pain"; 10 = "worst imaginable pain") following each posture, movement or task. All participants were notified of their right to decline to complete (or continue with) any activity that they felt increased their discomfort beyond a reasonable level. All subjects were debriefed following the session and provided with an information and exercise sheet containing advice on managing mild soreness as a result of the movements. Patients were also provided with a contact number to contact the lead researcher should acute pain arise as a result of the study. A potential allergic response to the electrodes or reflective markers was identified as a potential risk and was resolved by ensuring the subject was asked about allergies prior to data collection. EMG cables were identified as a potential tripping hazard, therefore cable positioning was highlighted to the subject to increase awareness and cables carefully placed for each task to minimize the risk of tripping. No adverse effects or hazards were observed on completion of the study.

6.5 Patient Reported Measures

All subjects completed six patient reported questionnaires: VAS (Von Korff et al. 1993), Oswestry Disability Questionnaire (ODQ) (Fairbank et al. 1980), STarT Back Tool (Hill et al. 2008), Distress and Risk Assessment Method (DRAM) (Main et al. 1992), TSK (Miller et al. 1991) and the International Physical Activity Questionnaire – short form (IPAQ-SF) (Booth 2000).

The ODQ was developed for use in chronic back pain populations (Fairbank et al. 1980), to identify the level of disability experienced during activities of daily living (ADL) (Roland and Fairbank 2000). The ODQ has 10 sections relating to a specific area of daily living including: pain intensity; personal care; lifting; walking; sitting; standing; sleeping; sex life (if applicable); social life; and travelling. Subjects are required to select the most appropriate statement for each ADL (scored according to symptom severity) to provide an overall percentage score of disability (Roland and Fairbank 2000). ODQ scores have been shown to moderately correlate with pain reported using VAS (n=94, r=0.62) (Grönblad et al. 1993) and predict sitting and standing performance in symptomatic subjects (Fisher

and Johnston 1997). The questionnaire has excellent reported within-day reproducibility (n=22, r=0.99) (Fairbank et al. 1980) and high between-day reliability when retested at 4 days (n=22, r=0.91) (Kopec et al. 1996) and at a week (n=22, r=0.83) (Grönblad et al. 1993). Both the ODQ and the Roland Morris Disability Questionnaire (RMDQ), an alternative LBP disability questionnaire, are used extensively for clinical and research applications within this patient population (Roland and Fairbank 2000) and have been shown to be highly correlated with comparable test-retest reliability and internal consistency (Kopec and Esdaile 1995). Davidson and Keating (2002) compared the ODQ with four other methods of evaluating low back disability including the RMDQ, the Quebec Back Pain Disability Scale, the SF-36 Physical Functioning Scale and the Waddell Disability Index, and found the ODQ to be the most reliable and accurate in determining symptom change in subjects. In addition, Roland and Fairbank (2000) purport the ODQ to be more responsive to change in high levels of disability, when compared with the RDMQ, and therefore may be more clinically applicable and responsive to change in patients with persistent pain. The ODQ has therefore been selected as an appropriate outcome measure of LBP disability for this study and has previously been utilised in MDCS MCI studies (Astfalck et al. 2010a; Astfalck et al. 2010b).

The VAS and Numerical Rating Scale (NRS) are commonly used to determine uni-dimensional patient reported pain. The VAS is a 10cm line with the descriptors 'no pain' and 'worst possible pain' at each extreme where the patient is requested to mark a line at the point which best represents their pain (Hawker et al. 2011). The NRS utilises a similar approach, however uses a whole number numerical scale from 0-10 to reflect pain intensity (Rodriguez 2001). One advantage of the NRS is advantageous is the ability to directly compare that written scores with verbally reported pain scores during data collection. NRS scores have been shown to be more easily reproducible irrespective of literacy levels (Ferraz et al. 1990), whereas test re-test reliability of the VAS (conducted in rheumatic pain populations) demonstrated higher test re-test reliability scores in literate patients (r=0.94, p<0.001) compared to patients who are illiterate (r=0.71, p<0.001) (Ferraz et al. 1990). This highlights NRS to be more easily replicable compared to VAS and potentially allows for scores to be completed verbally (as opposed to written) if the subject has a limited comprehension of written English (Hawker et al. 2011). Chronic pain patients have also been shown to find the NRS more comprehendible and easier to understand (de C. Williams et al. 2000). Other studies however have found that NSCLBP subjects deem NRS to be less sensitive in highlighting the complexity of their pain experience (Hawker et al. 2008; Hush et al. 2010). It is therefore clear that a combined approach to pain quantification would be advantageous for this patient population. For this study a quadruple VAS, which combines the VAS and NRS, as proposed by Von Korff et al. (1993) (Appendix VI) was used to best reflect the overall pain experience. Four scales were used to evaluate pain: pain right now, pain at best, pain at worst and typical or average pain. The average of these 4 scores were calculated to define the overall pain rating for the individual. A study of post-operative pain by Jensen

et al. (2003) suggests a sub-grouping approach to VAS scores to combine scores into more broad pain categories: no pain (0-4mm), mild pain (5-44mm), moderate pain (45-74mm) and severe pain (75-100mm). To enable comparisons to be drawn during data analysis these parameters were used to compare pain intensity between groups and explore the impact of pain on spinal kinematic behaviour. Further to the formal completion of the VAS, a verbal pain score (out of 10) was also reported after completion of each functional task.

The Tampa Scale of Kinesiophobia (TSK) was developed to assess pain-related fear of movement in CLBP (Miller et al. 1991) and is an increasingly utilised tool in primary care (Swinkels-Meewisse et al. 2003b). The TSK consists of 17 items, scored on a 4 point Likert scale ranging from 'strongly disagree' to 'strongly agree', scoring 1-4 accordingly (with the exception of items 4, 8, 12 and 16 for which the scores are inverted). To obtain the overall score, answer values are summed, with the total possible total score ranging from 17 to 68. Test re-test reliability of the TSK to accurately record pain-related fear in acute LBP populations has been shown to be good (r=0.78, $p \leq 0.01$) when re-tested within 24 hours (Swinkels-Meewisse et al. 2003a). Vlaeyen et al. (1995) compared the TSK with a number of established psychological and pain measures. The scale was found to correlate with the 'catastrophising' elements of both the Pain Cognition List (r=0.58, $p \leq 0.001$ (one-tailed)) (Vlaeyen et al. 1990) and the Coping Strategies Questionnaire (r=0.41, $p \leq 0.001$ (one-tailed)) (Rosenstiel and Keefe 1983), as well as 'depression' as measured by the Beck Depression Inventory (r=0.50, $p \leq 0.001$ (one-tailed)) (Beck et al. 1979) in CLBP populations. Understandably, lower correlations were observed with regard to pain when compared with the VAS (r=025, $p \leq 0.01$) as reported pain is not a primary outcome of the TSK, however the correlation was still found to be significant suggesting TSK may demonstrate some sensitivity to reporting pain (Vlaeyen et al. 1995). Vlaeyen et al. (1995) additionally observed that during a behavioural approach test (standing and sustained lifting a 5.5kg weight) patients with high TSK scores (>37) had greater tendency to avoid motor activities (i.e. cease activity earlier) compared to lower scorers. Whether patients with differing MCI patterns exhibit similar fear-avoidance strategies, and whether the TSK is responsive to these differences, remains unclear, therefore the TSK has been included to greater explore the impact of fear-avoidance on spinal kinematic behaviour.

The STarT Back Screening Tool (Hill et al. 2008) was developed to sub-group NSCLBP patients according to factors which increase the risk of chronicity including: referred leg pain, comorbid pain and disability. Five additional items exploring psychosocial factors are additionally considered as a sub-scale including: bothersomeness, catastrophising, fear, anxiety, and depression. The tool can be completed and scored quickly, categorising NSCLBP patients as high, medium or low risk of chronicity (Hill et al. 2008). The tool has been found to be excellently correlated with the Örebro Musculoskeletal Pain Screening Questionnaire (ÖMPSQ) (r=0.802 (total scores), r=0.769

(psychosocial scores)), although fewer subjects were defined as 'high risk' using STarT Back compared to the ÖMPSQ (Hill et al. 2010). Thus the approach has been identified to be comparable to the ÖMPSQ in defining sub-grouping characteristics, such as catastrophising, fear, comorbid pain, disability, and time off work consistently across low, medium and high groups; however the STarT Back tool has been shown to better discriminate for pain 'bothersomeness' and referred leg pain (Hill et al. 2010). Similarly, scores have been shown to highly correlate with the RMDQ for disability (r=0.813), and TSK for fear of movement (r=0.659 (psychological subscale)) (Hill et al. 2010). For the purpose of this study, the STarT Back Screening tool was included to evaluate whether baseline differences in the subgrouped MCI patients existed. If differences in biomechanical attributes are present between groups this may enhance understanding and inform intervention for these prognostic subgroups.

Psychosocial factors have been highlighted as a key factor in pain chronicity and have been shown to be important determinants of how effectively chronic pain patients respond to intervention (Burton et al. 1995). The DRAM is a simple, clinically useful approach to assessing and subclassifying psychological distress in patients to identify patients who may be at risk of, and those in, distress. DRAM consists of two questionnaires: the modified ZUNG Depression Index (MZDI) and the Modified Somatic Perception Questionnaire (MSPQ) (Main et al. 1992). DRAM is a clinical tool to flag up patients who may require more comprehensive assessment on the basis of psychological distress (Main et al. 1992). It is proposed to have been developed based on simple, validated LBP tools (Main et al. 1992) and subclassifies patients into 4 groups: those with no signs of psychological distress; those at risk of psychological distress; and those currently distressed (either depressive or somatic) (Main et al. 1992). Burton et al. (1995) identified that in a LBP population (n=252) sub-chronic individuals (those who experience pain >3 weeks, < 1 year) demonstrated only marginally higher incidences of psychological distress when compared with acute pain patients (pain <3 weeks) (21.4% vs. 17.4%) evaluated using DRAM. However, interestingly, the sub-chronic group consisted of a significantly greater proportion of individuals classified as 'at risk' of psychological distress. DRAM has therefore been included to evaluate baseline differences in psychosocial factors in this patient cohort.

The International Physical Activity Questionnaire (short form) (IPAQ-SF) (Booth 2000) was completed by all participants (healthy control and NSCLBP) to match for physical activity levels. The IPAQ questionnaires (long and short format) were developed in 1998 by a panel of international experts to address inconsistencies in physical activity reporting worldwide (Craig et al. 2003). The IPAQ-SF requires the subject to identify the duration and intensity of physical activity over the previous 7-day period. Subjects are required to self-report for 4 areas of activity: sitting, walking, moderate activity (e.g. carrying light weights, cycling at a normal pace, doubles tennis, etc.) and

vigorous activity (e.g. heavy manual lifting, aerobics, cycling at a fast pace, etc.) (Craig et al. 2003). The total number of minutes each activity was conducted for (per day) and the number of days over the previous week that the activity occurred is also recorded. A defined formula (Appendix VI) can then be used to determine the number of MET-minutes/week, which is converted into high, medium or low activity levels using specific criteria (Appendix VI). A significant advantage of this approach is that the questionnaire does not discriminate between specific activities but provides an overview of an individual's general activity level. Good test-retest (within week) repeatability has been observed with 75% of the correlation coefficients observed above 0.65 (r=0.32-0.88) using the IPAQ concurrently across 12 countries (Craig et al. 2003). Concurrent validity, comparing between long and short versions of the forms was also good, 0.67 (95% CI 0.64–0.70) (pooled) and 0.58 (0.51–0.64) when comparing between short forms alone. In contrast, criterion validity, assessed against accelerometer data, has been found to be consistently fair for the IPAQ-SF throughout the literature. Craig et al. (2003) observed fair to moderate agreement between the measures (n=781, median=0.30, 95% CI 0.23–0.36). Utilising similar methodology to establish criterion validity, Ekelund et al. (2006) similarly reported a modest correlation with accelerometry (r=0.34, $p<0.001$). These findings have more recently been further replicated by Medina et al. (2013). A review of validity studies for the IPAQ-SF by Lee et al. (2011) found that the IPAQ-SF overestimated physical activity (when compared against objective criterion) by an average of 84%, which was similarly observed by Ekelund et al. (2006) for estimation of time spent conducting physical activity as reported using the IPAQ-SF (mean difference: -25.9^{-1} min day, 95% limits of agreement: -172 to 120 min day^{-1}; $p<0.001$). Although these findings suggest the questionnaire must be utilised with caution, Ekelund et al. (2006) highlights that although the sensitivity of the tool appears to be low, IPAQ-SF can acceptably classify individuals achieving current physical activity guidelines. Additionally the authors comment that observed scores were unaffected by age, gender, BMI or education level. However, further evaluation has reported the IPAQ-SF to be a reliable and valid approach to quantifying durations of walking behaviours (van der Ploeg et al. 2010) and although there is limited application of the tool for intervention monitoring, the short form has been highlighted as a useful tool for population monitoring (Craig et al. 2003). The purpose of exploring physical activity as an outcome measure for this study was to ensure that the FP, AEP and healthy control groups could be matched for physical activity to identify potential discrepancies between populations. Thus this tool is reliable and valid for this purpose.

6.6 Piloting

Prior to data collection extensive piloting of the protocol and marker set were undertaken. Initially a number of marker sets (based on previous literature) were evaluated to establish the optimal number of spinal markers that could be used reliably. 'Swapping' of markers can occur where cameras are unable to distinguish between two markers placed closely together causing trajectories 'cross' over. Establishing a marker set with minimal 'cross-talk' from adjacent markers was therefore considered a priority. Piloting revealed that markers could not be placed on each spinous process due to an inability of Vicon® to distinguish between closely placed markers therefore spinal markers placed on every alternate spinous process was deemed practical to evaluate regional spinal movement.

Previous studies have used an S2 marker to evaluate the lower lumbar spinal angle (Hidalgo et al. 2012) or defined S2 as a key anatomical landmark if using an electromagnetic device such as 3Space Fastrak® (Dankaerts et al. 2006c; Mitchell et al. 2008). Due to the presence of the PSIS markers to establish the pelvis reference angle a marker could not be directly placed over S2 due to the close proximity of markers. Evaluation of several cadaveric lumbo-pelvic complexes revealed that in the majority of cases PSIS' were directly aligned with S2, or S1 (or the S1/S2 joint line) in a minority of cases. This finding is supported by Chakraverty et al. (2007). In light of the difficulties highlighted through the piloting process, to record lower lumbar angle consistently with previous literature (L3 to S1/2) a 'virtual' S2 marker was subsequently calculated as the midpoint between the PSIS' (section 5.4.2).

A secondary aim of piloting was to establish that all markers were visible to the cameras at all times. During flexed tasks the ASIS' markers and sternal marker were obscured. For this reason, a MATLAB code was developed to establish ASIS position from iliac crest and PSIS co-ordinates (through a calibration trial) to approximate the gap filling procedure when the markers were obscured. This same procedure was employed to approximate the sternal marker position from the acromioclavicular joint markers and C7. Piloting also identified that some marker positions moved closer together during certain movements (e.g. L2 and L4 markers in full extension). This was unavoidable, however this should to be taken into consideration when interpreting the data. Participants were requested to wear a head band with 4 reflective markers equally spaced during data collection to provide data on cervical rotation during functional activity, however patients hair often obscured the markers and the time requirement for gap filling was excessive. Therefore, the head markers were not processed for analysis in the current study due to time constraints, although the data was collected for future analysis.

6.7 Instrumentation

6.7.1 Spinal Kinematics

An eight-camera 3D motion analysis system (Vicon 512 Motion Systems Ltd, Oxford, OX2 0JB) evaluated sagittal spinal angle in 2 main spinal regions (total thoracic and total lumbar spine) and 4 sub-divided spinal regions (upper and lower thoracic spine, upper and lower lumbar spine) (Figure 11) using a novel spinal marker set, designed by Cardiff University, UK (Figure 13). A detailed description of the marker set is given in section 5.4.

Vicon® (Vicon 512 Motion Systems Ltd, Oxford, OX2 0JB) consists of 8 infrared wall-mounted cameras. Reflected light from retro-reflective markers is detected by each camera to establish the 2D marker position. Calibration of the cameras combines 2D information, from each camera, to establish 3D co-ordinates of each marker to enable the marker positions to be tracked and visualised in real-time. Prior to data collection the capture area was calibrated using a calibration T-wand (Vicon®) to ensure each camera is appropriately positioned and calibrated to easily identify markers within a defined area of interest. When using optoelectronic devices 'ghost' markers (faux 'marker' trajectories from reflections within the data collection area) can appear which need to be manually deleted. To minimise this risk standardised procedures were followed to mask all reflective surfaces in the room erroneously identified as markers.

Spherical retro-reflective markers (10mm) were placed over anatomical landmarks using double-sided marker tape (Section 5.4) with data captured at 100Hz, which is representative of other studies evaluating spinal posture (Blondel et al. 2012), spinal ROM (Vismara et al. 2010) and lumbar angle during lifting tasks (Kang et al. 2013). The 2D marker positions from each camera were displayed on the Vicon® workstation. Since all cameras are calibrated, the cameras' 2D marker co-ordinates are combined to create a visual 3D model of the marker trajectories for the whole movement. Markers (visualised on screen) were manually labelled to create link segments from which between segment angles were calculated. Accuracy of the Vicon® system has been suggested to be excellent (63±5μm) with overall precision 'noise' levels detailed to be approximately 15μm (Windolf et al. 2008), dependent on the environment in which the data collection is conducted and the quality of calibration. These factors are further discussed in section 2.6.1.

The systematic review (Chapter 4) highlights the rationale underpinning the development of the novel spinal marker set utilised in this study. Reliability of the marker set in healthy individuals is reported in Chapter 5.

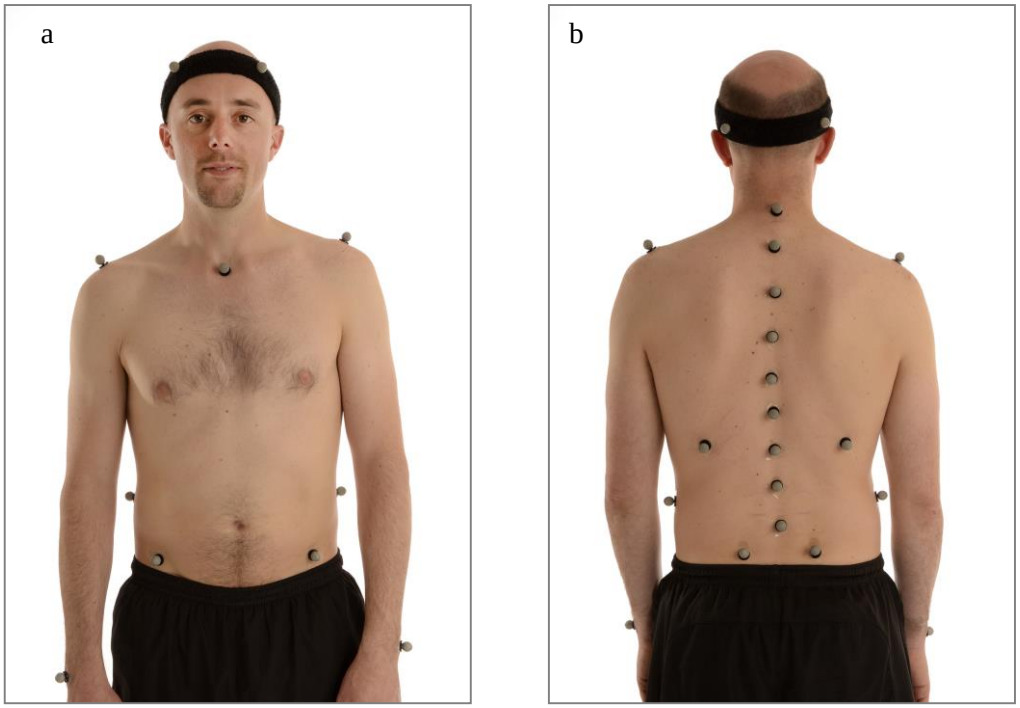


Figure 13: Novel marker set a) anterior view, b) posterior view

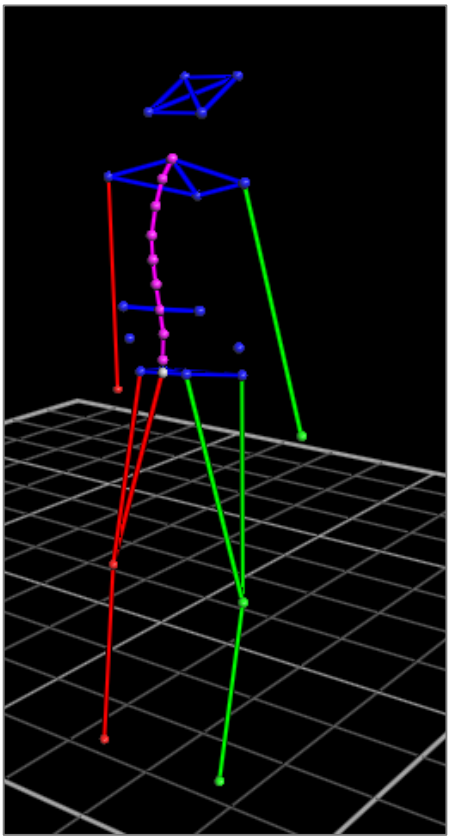


Figure 14: Labelled marker set as visualised in Vicon®

There is currently no definitive consensus on the correct approach for spinal palpation with the reliability and reproducibility of spinal palpation varying greatly throughout the literature (Kilby et al. 2012), however Miller et al. (1992) proposes that the 3 most readily identifiable landmarks for the spine and pelvis are C7, the iliac crests and the "dimples of Venus". The location of C7 has previously been defined as the vertebra with the most prominent spinous process at neck level during cervical flexion (Miller et al. 1992) and most easily identified (Vergara et al. 2006). To identify C7 the subject was requested to "bend their head forward" whilst in standing, the most prominent spinous process palpated, the position maintained whilst the subject returned their head to a neutral position and then a marker was placed at that point to define C7 (Vergara et al. 2006). From the C7 anatomical landmark every other spinous process was palpated caudad to L4 (T2, T4, T6, T8, T10, T12, L2, L4). The L4 marker position was cross checked by the placing hands horizontally over the most superior aspect of the iliac crests to define the line between them (the intercristal line) (Vergara et al. 2006). Traditionally this line has been reported to correspond with the level of L4, however Chakraverty et al. (2007) found this level to be L3 or L3/4 in 77% of subjects when comparing surface palpation with prone fluoroscopy. Therefore if this line intersected with the L4 spinous process or intersected halfway (or below) the space between the L2 and L4 markers the position was deemed acceptable and no further alteration to the marker position was deemed necessary.

As subjects are required to move through full range of spinal flexion and extension in standing positions, markers were applied to the skin with the subject in a neutral standing position, as this posture was considered to best reflect the spinal position under investigation without direction specific bias. The degree to which skin artefacts affect sagittal spinal angle, in comparison to a gold radiographic standard (usually MRI), is highly variable throughout the literature. Mörl and Blickhan (2006) found differences of up to 9.86mm at L3 and L4 during rotation of the shoulder (90 degrees) during sitting, whilst Heneghan and Balanos (2010) reported differences of up to 16mm at the level of T1, T6 and T12 in seated rotation (to 35 degrees) and up to 1.5mm in unilateral upper limb elevation in sitting. Whereas Zemp et al. (2014) found more significant differences of up to 27.4mm in static sitting. In contrast Vergara et al. (2006) noted that when moving from an erect to a flexed seated posture skin movement artefact at C7 was noticeable (mean 15.8 mm, SD 8.5 mm) however at L5 and L1-T12 displacements were negligible (mean 3.1 mm, SD 3.4 mm, mean 4.7 mm, SD 4.0 mm respectively). This variance in soft tissue artefact error on spinal motion needs to be considered in this study, however, due to the single session study design and standardized protocol (same tester) the ability of the marker set to identify between group differences in movement patterns of the spine using this equipment should be highly specific. It is acknowledged that the degree to which the results obtained reflect the true movement of the underlying vertebral bodies is inherently limited. The aim of

the study was therefore to detect external spinal curvature rather than reflect accurate vertebral motion.

6.7.2 Electromyography

Electromyography data was collected through an 8 Channel Bortec EMG system (Octopus Cable Telemetric System, Bortec Electronics Inc., Calgary, Alberta, TH3H 3G6, Canada), synced with Vicon® to provide real-time muscle activity data alongside the kinematic data. sEMG recorded spinal extensor (sLM and LT) and abdominal (TrA/IO and EO). muscle activity. These muscle groups have previously been explored in these MCI subgroups and thus aid in providing a comparable data set (Astfalck et al. 2010b; Dankaerts et al. 2006a; Dankaerts et al. 2004).

Following SENIAM guidelines (Freriks and Hermens 1999), the following parameters were used to record sEMG of the trunk muscles. A differential pre-amplifier with fixed gain of 500, input impedance of 1OGOhm, common rejection ratio set at 115 dB and a frequency response of 10Hz to 1000Hz was used, which is a protocol representative of other studies investigating functional movement in these patient populations (Dankaerts et al. 2004; Sheeran et al. 2012). The signal was amplified further by a gain of 2000 using a 20Hz high pass filter to suppress any potential movement artefacts. The raw signal was full-wave rectified and band pass filtered (with zero phase lag and 20Hz cut-off frequency) using 2nd order Butterworth filter and a linear envelope for each channel. This was achieved using a custom-developed MATLAB routine. Visual inspection of the sEMG data was conducted in real-time during the data collection session through the use of an oscilloscope within the Vicon® software.

To minimise the risk of 'cross-talk' and ensure that electrodes are positioned accurately and are sensitive to the specific muscle activity in question, The European Recommendations for SENIAM (Freriks and Hermens 1999) were used to define the exact location of electrodes for the sLM and LT muscles investigated. Since the SENIAM guidelines do not outline electrode positions for TrA/IO and EO, EO electrode positions were placed as described previously in the literature (Dankaerts et al. 2006a; Ng et al. 1998). For TrA/IO electrode placement sites were defined in line with a procedure defined by Marshall and Murphy (2003) as this specific site has been shown to accurately record TrA/IO activity and has been shown to be highly reliable in replicating muscle activity between days.

Factors that are known to impact upon the reliability of electromyography are impedance of the skin, perspiration and body hair (De Luca 1997; Konrad 2005; Lehman and McGill 1999). These factors were controlled by ensuring the skin was: shaved and thoroughly cleaned using alcohol wipes;

temperature in the room was controlled; and impedance tested using an impedance meter. Impedance was considered to be at a satisfactory level if <10kOhm (Hermens et al. 2000; Konrad 2005). Cross-talk (or 'noise') can also be produced from adjacent muscle activity detected by the electrodes, as well as being influenced by the inter electrode distance (Konrad 2005). Therefore dual electrodes (Noraxon USA Inc., Arizona, USA) were used to improve muscle activity selectivity and standardise inter-electrode distance (20mm) (Freriks and Hermens 1999). sEMG has been shown to be comparable with fine-wire EMG for the evaluation of TrA/IO and EO in healthy individuals, with McGill et al. (1996) identifying <15% difference in Root Mean Square in these muscle groups. This has similarly been observed in TrA (Marshall and Murphy 2003). Care must be taken with correct electrode placement for sLM. It is well established that in order to detect activity of the deep fibres of LM, fine wire EMG is required to accurately report muscle activity (Stokes et al. 2003). Due to the ethical implications of using fine wire EMG and access to resources, sEMG electrodes were used to evaluate all muscle groups, thus for LM it is important to highlight that all muscle activity relates to 'superficial' fibres of LM only. Additionally the potential for 'cross-talk' from the LT musculature must be noted as a potential contributor to the LM recording as highlighted by Stokes et al. (2003).

MacDonald et al. (2009) used intramuscular electrodes alongside sEMG with which to evaluate LM in patients in remission from recurrent LBP. Although no difference bilaterally was observed in healthy individual, significant differences between sides of the lumbar spine were observed in patients with unilateral LBP. For this reason, sEMG was recorded bilaterally in the current study.

EMG amplitude can vary greatly between individuals and electrode sites thus sEMG needs to be normalised for each individual (Konrad 2005; Lehman and McGill 1999). In order to normalise sEMG data, the total muscle activation during the test condition is expressed as a percentage of the total muscle activity in a standardised condition. This is essential in order to evaluate and standardise data to determine differences between subjects and muscle groups, and also to provide a comparative platform from which to compare with similar studies (Knutson et al. 1994; Lehman and McGill 1999; Mirka 1991). Typically this is determined by comparison to the maximum voluntary contraction (MVC) of the muscle group under investigation, however studies evaluating the reliability of MVCs in CLBP have shown poor reliability (Ng et al. 2002b). Dankaerts et al (2004) showed that MVCs demonstrated low reliability when repeated between-days (ICC mean 0.70; range 0.19-0.99) in both a healthy and symptomatic cohort. In contrast, SMVCs demonstrated excellent within-day (ICC mean 0.91; range 0.75-0.98) and between-day (ICC mean 0.70; range 0.19-0.99) reliability, to suggest SMVCs to be a more reliable measure for sEMG when evaluating trunk musculature. Dankaerts et al's (2004) findings are supported by multiple studies similarly showing SMVC to be a reliable comparative measure when evaluating abdominal musculature (Allison et al. 1998; Larivière et al. 2002; O'Sullivan et al. 1998). It has been suggested that SMVC values are more reliable in trials

where levels of muscle activity are relatively low (Allison et al. 1998) as CLBP patients demonstrate lower levels of fatigue during MVCs compared with healthy individuals, thus potentially are less likely to achieve a maximal value due to the fear of pain provocation (Oddsson and De Luca 2003). It may be that the effort and associated pain involved in generating an MVC may inhibit the individual from expressing a true maximal effort (Vlaeyen et al. 1995). Therefore, as the use of SMVCs for the abdominal muscles has previously been defined, and validated as a reliable comparison for the normalisation of sEMG data when investigating the trunk muscles in pain populations (Dankaerts et al. 2004; McGill 1991) these will be utilised in this protocol.

6.8 Reference Postures

Reference values for usual standing, usual sitting, maximum flexion and maximum extension postures were collected to evaluate a baseline comparison for each subclassified group. Due to this study protocol patients are highly aware that their data is being recorded throughout and therefore usual sitting and standing posture cannot be measured covertly as previously described in the literature (O'Sullivan et al. 2010). Subjects were instead encouraged to adopt their natural, comfortable sitting and standing positions to minimise the risk of altering' their natural functional movement patterns. Data was recorded over a 10 second time frame for all usual sitting and usual standing postures, with data analysis using a time point exactly at 4-5 seconds into the trial to obtain average values. To ensure that neutral posture was obtained and standardised for the sitting trials plinth height was adjusted for each patient to ensure hips, knees and ankles were positioned at 90 degrees (measured using a goniometer) as a standardised start position (O'Sullivan et al. 2003; O'Sullivan et al. 2006b).

6.9 Functional Tasks

The functional activities chosen for this study reflect a cross-section of usual activities of daily living whilst also being representative of activities commonly reported to clinicians as pain provoking. The tasks chosen incorporate movements across a wide spectrum of spinal ROM (flexion, extension and rotation) to evaluate whether the ROM bias of each activity is influenced by the direction of pain provocation reported by the MCI sub-groups, and whether sub-groups display differences in spinal kinematics and muscle activity throughout the tasks.

Significant differences in lumbar flexion angle have been observed between sit-to-stand, stand-to-sit and picking an item up off the floor ($p<0.001$) indicating that these functional tests are sensitive enough to evaluate different ranges of movement in healthy individuals (Hsieh and Pringle 1993).

Picking an object off the floor has been found to require almost full lumbar flexion (95%) in healthy individuals (Hsieh and Pringle 1993), findings which are supported by Bible et al. (2010) who noted that picking up an item up from the ground was found to require the greatest lumbar ROM (of a battery of activities tested) regardless of whether the subject adopted a squatting or bending technique. Therefore the activity of picking up an item from the floor, using a self-selected technique was included in this study as a functional task for which the subjects will have to adopt more end range flexion postures. Sitting and standing postures are often clinically reported as aggravating, pain provoking postures by patients, therefore, sitting-to-standing and standing-to-sitting were chosen as functional tasks as they incorporate both of these aggravating postures.

Flexion and rotation whilst lifting is also often clinically reported as a pain provoking activity for CLBP patients with workers exposed to combined flexion, rotation and lifting postures for more than 5% of their working day shown to increase their risk of developing LBP (Hoogendoorn et al. 2000). To replicate this movement pattern a weighted box was used to 'load' the spine whilst in a flexed and rotated position. It is acknowledged that symptomatic subjects may habitually avoid this posture and find alternative strategies to conduct the activity (i.e. minimising trunk rotation by moving the feet accordingly), however to ensure potential biomechanical differences between individuals could be evaluated the procedure was standardised. Patient-selected performance of this activity may have produced a data set which is more representative of the wider population however the increased sample size required to conduct such a study are beyond the feasibility of this PhD project and thus the standardised approach was employed.

Reaching was chosen as a frequently performed activity requiring the thoracic and lumbar spine to adopt a more extended posture. Differences in neuromuscular control of the trunk during reaching have been identified in CLBP patients (of mechanical origin) compared with healthy individuals (Silfies et al. 2009a) which has been hypothesised to be due to reduced control of the trunk extensor musculature in this patient population, and thus an important task to be evaluated.

Ascending and descending stairs is another important activity frequently conducted by the majority of the mobile population and therefore step-up and step-down tasks were included. Other personal ADLs, for example washing hands, hair washing, shaving and applying make-up, have been shown to demonstrate similar percentages of total ROM of the lumbar spine compared to walking and ascending and descending stairs (Bible et al. 2010) so were not included due to the potentially limited additional clinical value.

An important consideration of the study was patient fatigue and pain provocation, therefore the number of overall tasks for completion during the data collection session was considered reasonable

to limit to 5, with a repetition of 4 for each task. The added value of the five tasks chosen was that all tasks could be sub-divided during the data processing stage (Table 6) to increase the number of activities evaluated, without fatiguing the patient or extending the data collection time beyond reasonable limits.

Hsieh and Pringle (1993) found that different strategies were employed by healthy individuals when performing a variety of functional activities, therefore the protocol required for each activity needed to be carefully considered, to allow for natural functional movement which was reflective of habitual behaviour. Additionally the protocol needed to ensure standardised procedures were adhered to evaluate sagittal spinal angles independently of the subjects' global approach to movement. The within-day reliability results for both the spinal kinematics and sEMG are reported in the main study results (Chapter 7) to outline the natural variability of movement in both the healthy and symptomatic groups across repeated trials.

6.10 Variables

The independent variables for the study were patient subclassification, either FP-MCI or AEP-MCI and the functional task. The dependent variables were the sagittal spinal angles in the following spinal regions: total thoracic; total lumbar; upper thoracic; lower thoracic; upper lumbar; and lower lumbar; and trunk muscle activity obtained via surface electromyography. An overview of these variables is given in Figure 20.

6.11 Data Collection

6.11.1 Experimental Protocol

All testing was performed in a single visit at the Research Centre for Clinical Kinesiology (RCCK), School of Healthcare Sciences, Cardiff University, Wales, UK. Each data collection session took approximately 90-120 minutes to complete. Figure 15 outlines the study protocol for the healthy control and NSCLBP groups.

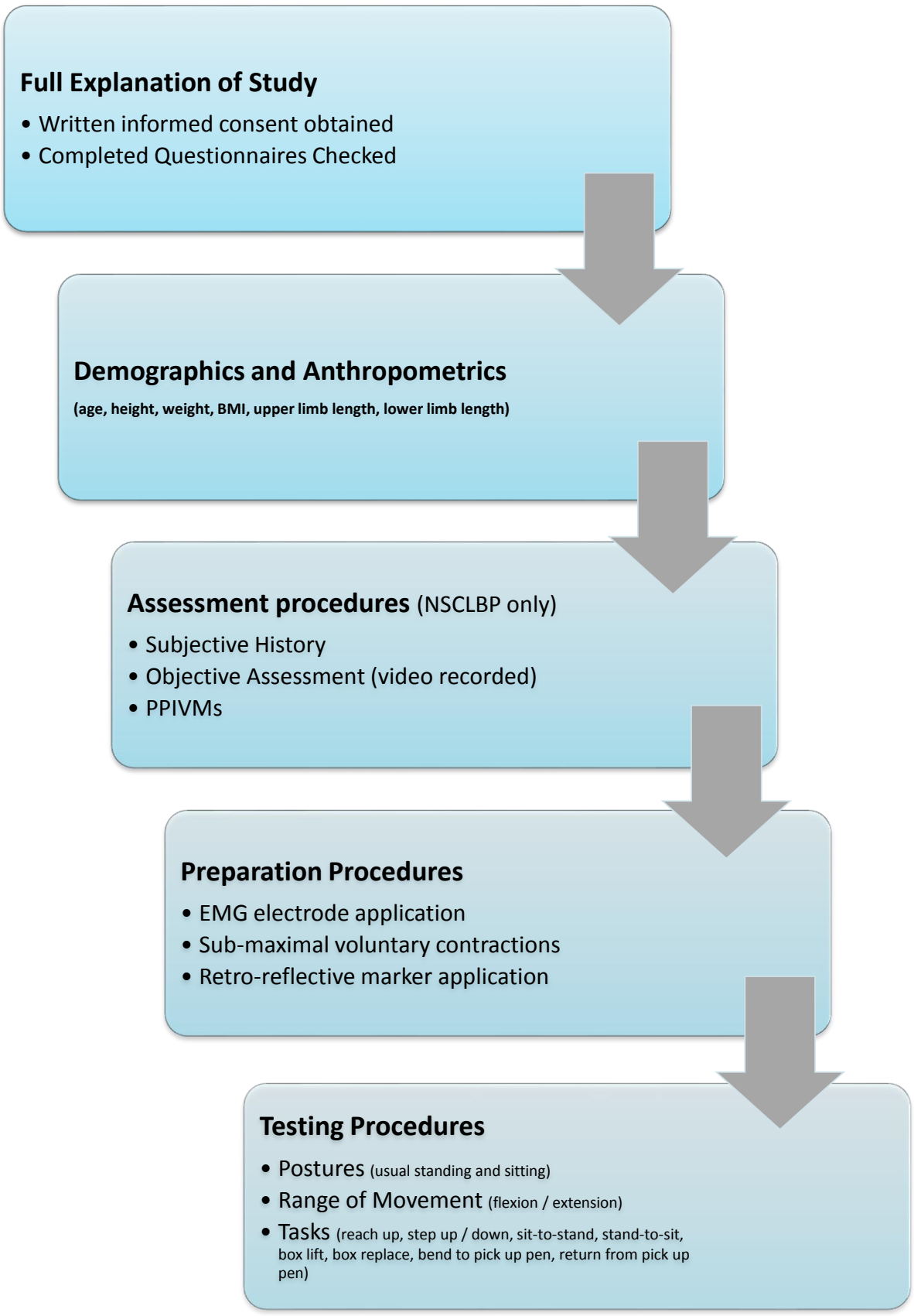


Figure 15: Flow diagram to outline the main study protocol (for NSCLBP and healthy control)

6.11.2 Questionnaires

Questionnaires (VAS, ODQ, STarT Back, TSK, DRAM, IPAQ-SF) were posted to each NSCLBP participant prior to attending the session, to reduce data collection time and minimise any influence in answering questions in the presence of the researcher. Patients were requested to complete the questionnaires and bring them to the data collection session where the NISCHR research officers addressed any queries and the questionnaire answers were checked for completeness. All incomplete questionnaires were completed in full prior to data collection.

6.11.3 Demographics and Anthropometrics

The subject's date of birth and gender was recorded on each data collection sheet. For each subject height and mass measurements were recorded to obtain their BMI score. Mass was measured using digital floor weighing scales (Seca 888, Seca Ltd., Medical Scales, Birmingham, UK). Height was measured using a mechanical telescopic measuring rod (Seca 222, Seca Ltd., Measuring Systems, Birmingham, UK). Subjects were instructed to remove shoes and socks for height and mass measurements. Bilateral upper limb length (acromion process to distal end of middle finger) was recorded to accurately define a standardised target position (for box placement) for the box rotation task. Additionally lower limb length (ASIS to medial malleolus) was recorded bilaterally using a tape measure to assist with the Bodybuilder model (Vicon Nexus). For each subject the equipment used was individually height adjusted (Section 5.4.1).

6.11.4 Clinical Assessment

For NSCLBP subjects, history of the present condition, pain behaviour (24 hour pattern and pain description), any relevant past medical history (in case of significant co-morbidity), social history (including occupation, hobbies, sports etc.) and a detailed recording of pain provoking and easing factors, were recorded.

The objective assessment consisted of usual standing, full lumbar spine ROM in standing (including lumbar spine flexion, extension and side flexion bilaterally), standing on one leg, usual sitting, slumped sitting, upright sitting, sit-to-stand and gait (if applicable i.e. if FLSP or MDP MCI was suspected) (O'Sullivan 2000; O'Sullivan 2004). The subjects gave verbally reported pain score for each movement and if appropriate indicated the region of pain. All movements and verbal commentary were recorded simultaneously by video camera in the sagittal plane and frontal plane (posterior view) for later analysis by the 2nd researcher to assist with MCI subclassification.

PPIVMs were performed on each NSCLBP subject in side lying (O'Sullivan 2000, 2005; O'Sullivan 2004), at the level of, above and below the level of pain to identify any presence of hypo or hypermobility.

6.11.5 Preparation Procedures

6.11.5.1 Electromyography

To prepare the subject for sEMG of the anterior muscles (TrA/IO and EO), the patient lay supine on the plinth. For the posterior muscles (sLM and LT), the subject lay prone on a plinth with a pillow placed under the patient's stomach to achieve slight lumbar flexion, as per the SEMIAM guidelines (Freriks and Hermens 1999). The skin was prepared through initial shaving and cleaning of the area thoroughly with alcohol wipes (UHS, Enfield, UK) (Freriks and Hermens 1999). Skin impedance was tested using an impedance monitor (Noraxon, Arizona, USA) (Konrad 2005).

Disposable, self-adhesive Ag/AgCl dual snap electrodes (Noraxon, Arizona, USA) with two circular conductive surface areas of $1cm^2$ and a standardised inter-electrode distance of 2cm were placed parallel to the muscle fibres of LM, LT, TrA/IO and EO muscles bilaterally.

The dual electrodes were aligned with the muscle fibre orientation of each muscle (Dankaerts et al. 2004). Electrodes for LT were placed vertically at a point 2 finger widths laterally from the spinous process of L1. For sLM electrodes were placed 2-3cm from the midline (aligned with a line from caudal tip of the PSIS' to the interspace between L1 and L2) at the level of the L5 spinous process (Freriks and Hermens 1999). For EO the electrodes were placed slightly inferior to the rib cage along a line connecting the most inferior point of the costal margin and the contralateral pubic tubercle (Dankaerts et al. 2006a; Dankaerts et al. 2004; Ng et al. 1998). For TrA/IO the electrodes were placed approximately 2cm medially and inferior to the ASIS (Marshall and Murphy 2003). An earth electrode was placed over the left iliac crest. The subject wore the sEMG battery pack on a belt (Figure 16), over the left hip such that the pack did not obscure markers or obstruct movement. The pack was linked to the main amplifier through a single fixed cable. Snap electrode leads were attached to each electrode, which were secured to the skin using hypoallergenic micropore tape (Micropore, 3M Healthcare, Nuess, Germany) to avoid excessive movement of the leads and subsequent risk of additional "cross-talk" (Dankaerts et al. 2004).

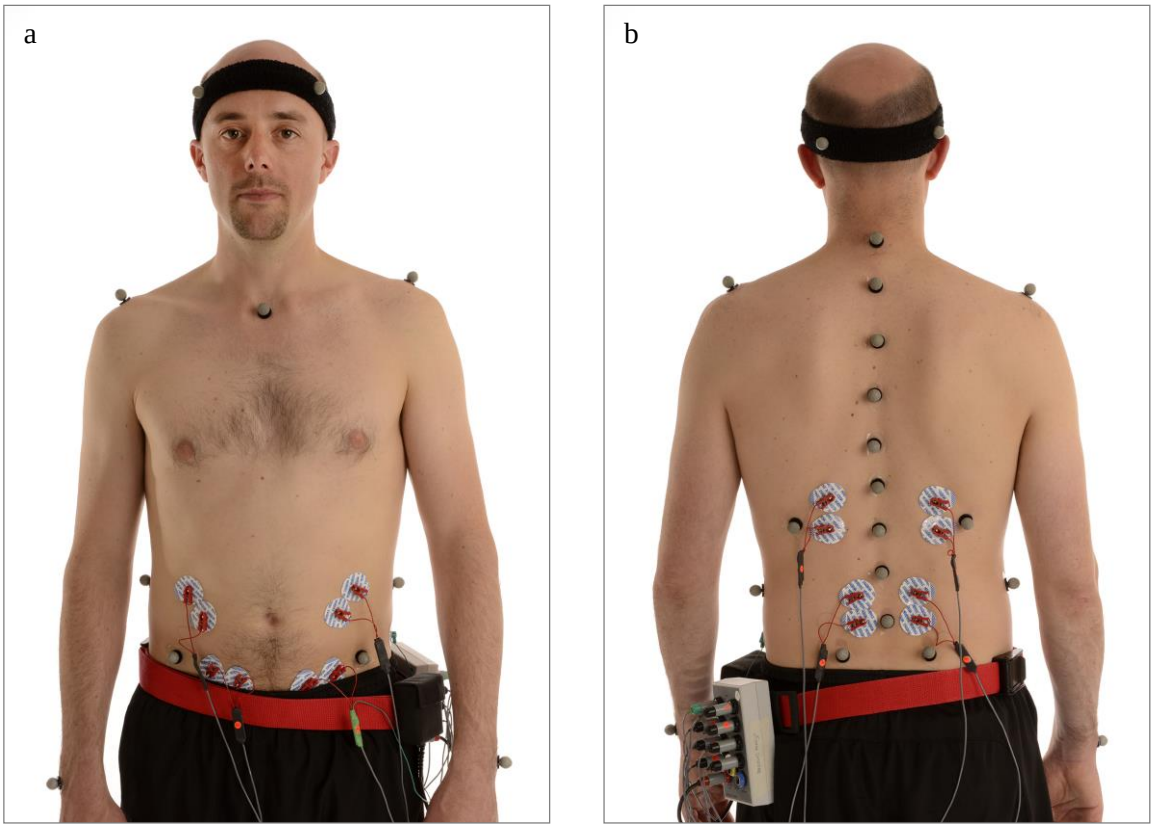


Figure 16: Electrode placement a) abdominals, b) extensors

Each muscle was assigned to a specific channel as follows:

Channel 1: Left Transversus Abdominis / Internal Oblique (plus earth electrode)

Channel 2: Right Transversus Abdominis / Internal Oblique

Channel 3: Left External Oblique

Channel 4: Right External Oblique

Channel 5: Left superficial Lumbar Multifidus

Channel 6: Right superficial Lumbar Multifidus

Channel 7: Left Longissimus Thoracis (Erector Spinae)

Channel 8: Right Longissimus Thoracis (Erector Spinae)

Following application of electrodes, sEMG signal was checked using an oscilloscope in the graph-viewing pane in Vicon®, to ensure that the signals for each muscle were being accurately observed. Resting sEMG for the abdominal muscles was recorded with the subject lying relaxed in supine over a 5 second time period to ensure no anomalies in the sEMG trace could be visually identified at rest (Konrad 2005). This procedure was repeated for the sLM and LT muscles in prone lying. To standardise sEMG data, data was normalised to SMVC. Each SMVC was recorded over a period of 3 seconds with a minimum of a 30 second break between trials to avoid fatigue and symptom aggravation (Dankaerts et al. 2004; Soderberg and Knutson 2000). A crook-lying double leg raise was used to achieve SMVC of the abdominal muscles. Subjects lay in crook-lying (knees approximately 90 degrees, hips approximately 45 degrees) and were instructed to lift their feet approximately 1cm off the bed and hold the position for 3 seconds (Allison et al. 1998; Dankaerts et al. 2004; Twomey et al. 1997). For the LT and sLM muscles, SMVC values were obtained from a prone lying double knee lift, with the subject lying prone on the plinth, knees bent to 90 degrees. The subject was instructed to lift their knees 5 cm off the bed and maintain the position for a period of 3 seconds (Dankaerts et al. 2004). Each SMVC was repeated until 3 good quality data trials had been recorded.

6.11.5.2 Spinal Kinematics

An 8-camera 3D motion analysis system (Vicon 512 Motion Systems Ltd) was used to record spinal kinematics (100Hz) using a novel spinal marker set (Cardiff University). The Vicon® system was calibrated statically using a T-wand (Vicon®) to calculate the centre of the capture volume area and then dynamically by moving the wand throughout the full volume of data collection area to enable the system to calculate the relative positions and orientations of the 8 cameras. The system was then resynchronised to ensure the motion analysis and sEMG components were accurately synced.

In order to establish a consistent approach the same clinician, a chartered physiotherapist (RH) with 4 years clinical experience and good anatomical knowledge and palpatory skills, performed all anatomical marker placement. Marker placement was conducted with the subject in standing. Marker positions are described in section 5.4. As discussed in section 5.4.2 it was deemed reasonable to be able to calculate a 'virtual S2 marker' as the intersecting point halfway between the PSIS markers as a standardised point on the sacrum, however it must be acknowledged that this arbitrary measure on the sacrum may correspond to S1 in a minority of cases (Chakraverty et al. 2007).

Once the sEMG set-up and marker application was complete, the Vicon® system was re-synchronised and data visually inspected to ensure all preparation procedures had been undertaken correctly. An

anatomical calibration was conducted with the subject stood, feet shoulder width apart, arms relaxed, in the centre of the capture volume area, to identify the local co-ordinates of the markers relative to each other in order to run the custom developed Bodybuilder files for gap filling marker trajectories (section 5.4.2).

6.11.6 Testing Procedures

To minimise possible researcher bias, a NISCHR research officer provided all data collection instructions to the participant following a standardised protocol (Appendix V). A 30 second rest period (minimum) between each testing condition was employed to ensure that fatigue did not become a confounding variable. This also ensured any pain response had settled prior to undertaking the next task. Where pain did not resolve to pre-task level the activity was ceased. The participant was given the opportunity to practice each movement once prior to the data collection to familiarise themselves with the protocol.

In order to effectively evaluate how consistently NSCLBP patients move within MCI subgroups, sufficient trial repetitions need to be conducted to establish within-group error and variability. Due to the nature of NSCLBP and the potential for symptom aggravation as the tasks progress, 4 repetitions for each task were deemed reasonable to minimise the risk of pain escalation, which could impact upon movement behaviour. To monitor this factor and prevent potential severe pain onset, verbally reported NRS scores were obtained from all NSCLBP subjects following each trial. Where pain was reported to be >7/ 10 the individual was asked whether they wished to continue with or cease the task. Due to volume of data required to be processed within the time constraints of this study, 3 of the 4 trials for each task were processed for each subject, however this is reflective of previous study protocols identifying regional spinal differences in back pain populations in functional activities (Mitchell et al. 2008; Shum et al. 2007a, b).

A trial recording the usual standing and usual sitting position for each subject was used to determine an individualised spinal anatomical position as a reference value for each functional task. Reference measures to determine total ROM for the spine were also collected for maximum flexion and extension in standing.

Five functional tasks were chosen to reflect a spectrum of tasks encountered in everyday living including: moving a weighted box from right to left; reaching to place a light weight (0.5kg) onto a shelf; bending to pick a pen up off the ground; stepping up onto a 6-inch Reebok® step and stepping forwards down off the box; and sitting to standing and returning to a sitting position.

Initially usual standing, flexion and extension in standing were recorded. Then the order in which the functional tasks were performed was randomly allocated (using pre-printed data collected sheets chosen at random) by either conducting 'sitting' activities (usual sitting and sit-to-stand-to-sit) followed by 'standing' activities (reach up, box lift and replace, step up and down, bending and returning from picking up a pen); or vice-versa. Each task was repeated until 4 good quality trials had been recorded. During data collection, the subjects' technique was visually monitored by a NISCHR research officer to ensure the task was performed correctly. The trial was repeated if a subject performed a task incorrectly, or if errors in the system occurred.

Following the completion of the tasks all markers and electrodes were removed. Skin was visually checked for redness to ensure no adverse effects had occurred. Participants were given a copy of the Back Book (Burton et al. 2002) and provided with an exercise sheet and appropriate advice regarding completion of exercises (Appendix V).

6.11.7Trial Protocols

Usual Standing

For the usual standing position, subjects were instructed to adopt their usual relaxed standing posture (feet shoulder width apart with their arms hanging freely), looking straight ahead at a standardised point on the wall for 10 seconds (Dankaerts et al. 2009).

Usual Sitting

For the usual sitting position, subjects were instructed to adopt their usual relaxed sitting posture (arms relaxed to the side) on a plinth set to a standardised height for the subject (hips and knees 90 degrees, thighs parallel to the plinth). The subjects were instructed to sit with their feet positioned shoulder width apart, looking straight ahead at a standardised point on the wall for 10 seconds (Dankaerts et al. 2009).

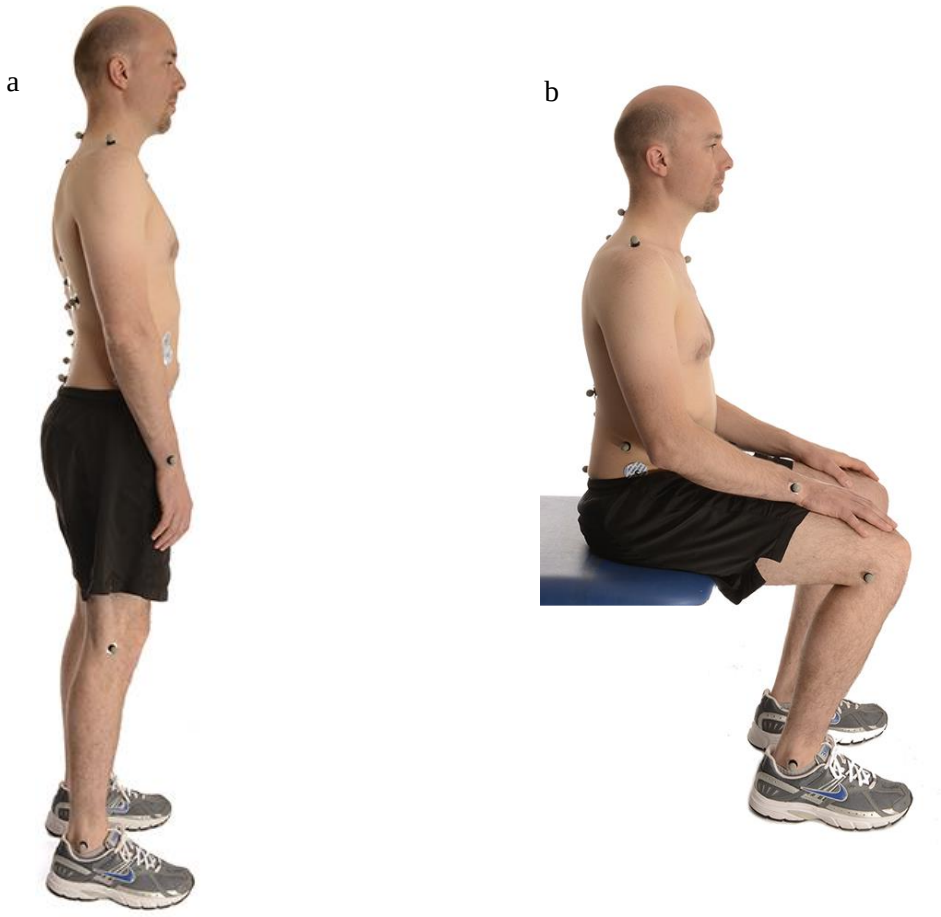


Figure 17: Usual standing (a) and usual sitting (b)

Full Flexion in Standing

Full flexion, through the subject's full range of trunk movement, was performed in standing. The subject was asked first to adopt their usual relaxed standing posture (as above) then 'bend forward' as far as possible, wait for a minimum of 1 second at the end of their available range, then return to their usual standing position. Participants were requested to bend as far as they could.

Figure 18: Full flexion in standing

Full Extension in Standing

Full extension, through the subject's full range of trunk movement, was performed in standing. The subject was asked first to adopt their usual relaxed standing posture (as above) then 'arch backwards' as far as possible, wait for a minimum of 1 second at the end of their available range, then return to their usual standing position. Participants were requested to extend as far as they could.

Figure 19: Full extension in standing

The protocols for the functional tasks have been described previously (section 5.4.1).

6.12 Data Processing

6.12.1 Spinal Kinematics

Data processing procedures for spinal kinematics are described in section 5.4.2.

6.12.2 Electromyography

Raw sEMG data, as defined previously was obtained for the TrA/IO, EO, sLM and LT muscles (bilaterally) during 3 SMVC trials (repeated for both extensor and abdominal muscle groups) and for 3 trials for each of the functional tasks (step down, step up, reach up, pick up pen (bend down), pick up pen (return), stand-to-sit, sit-to-stand, box replace and box lift). Functional tasks were the focus of the sEMG investigation as muscle activity during static postures has been evaluated and reported previously in AEP and FP populations (Astfalck et al. 2010b; Dankaerts et al. 2006a; Sheeran et al. 2012).

All raw sEMG data was exported into MATLAB. sEMG traces for each channel were visually inspected in MATLAB and any trials with excessive visually identifiable 'noise' were manually de-selected from the final analysis. Where the sEMG signal obtained during one trial for a task was poor, the trial was omitted from the final analysis and the remaining satisfactory trials for the task were averaged for inclusion in the final analysis. Processed sEMG data was saved in MATLAB (version R2013a). Normalised amplitude sEMG for each task was calculated and collated in a custom developed MATLAB programme. Data quality was initially checked visually through graphical output representation in MATLAB. Where any anomalies or 'noise' in the data were apparent, the raw sEMG was identified and discarded prior to being exported to an Excel file. Once the data was exported to Excel a secondary data check was completed. Finally the final data set was imported into SPSS.

The SMVC recording with the clearest raw sEMG signal for each muscle was selected for analysis. sEMG data for each side was normalised relative to the SMVC for each muscle (%SMVC) to calculate normalised sEMG amplitudes (%SMVC) for the right and left musculature. Normalised amplitude sEMG (%) was calculated as follows:

$$(\text{processed sEMG} / \text{SMVC}) \times 100$$

For each muscle group, muscle activity was recorded for both the right and left side. Preliminary analysis of these muscle groups using paired samples t-tests (Appendix IX) revealed bilateral

significant differences in normalised sEMG amplitude across tasks in the abdominal muscles. In contrast, the sLM and LT muscles revealed very few significant differences between normalised sEMG amplitude bilaterally. Due to the asymmetrical nature of the tasks, and the lack of bilateral consistency in muscle activity levels in the abdominal musculature, the normalised sEMG amplitudes for left and right were considered separately for each muscle group.

6.12.3 Questionnaires

Questionnaire data was manually scored and inputted into an Excel database. All questionnaire response data was double-checked for errors independently by a research assistant. For the ODQ an overall percentage score is calculated relative to the number of questions answered (Appendix VI). A percentage score of 0-20% indicates minimal disability, 21-40% moderate disability, 41-60% severe disability, 61-80% 'crippled' and 81-100% indicative of the patient being bed bound (or potentially exaggerating their symptoms) (Fairbank and Pynsent 2000). Average VAS scores were sub-grouped into four groups: No pain (0-0.4), mild pain (0.5-4.4), moderate pain (4.5-7.4) and severe pain (7.5-10) for ease of comparative analysis between groups. These parameters are based on recommendations for grouping VAS scores validated by Jensen et al. (2003).

To score the TSK, the total score is calculated after summing the individual scores with the exception of the individual scores of items 4, 8, 12 and 16, which are inverted (Miller et al, 1991). The range of total scores varies from 17 to 68, with higher values indicating greater kinesiophobia (Lundberg et al. 2004). For analysis subjects were grouped. Subjects scoring <37 overall were classified as demonstrating a low risk of kinesiophobia. High risk was determined as scoring => 37. Vlaeyen et al. (1995) have previously used this cut-off to subclassify CLBP subjects into high and low fear sub-groups. A similar cut off point has been proposed by Lundberg et al. (2004) in subclassifying kinesiophobia between more active and inactive groups of chronic back pain patients.

NSCLBP patients who scored 3 or less overall on the STarT Back were classified as low risk. If subjects scored 4-5 on the psychosocial sub-scale they were categorised as high risk. All subjects falling between these parameters were defined as medium risk (Appendix VI). For DRAM, the two questionnaires, MZDI and MSPQ, were scored in accordance with Main et al. (1992) (Appendix VI). This approach combines the scores of the two questionnaires to define whether the patient is distressed or potentially at risk of becoming distressed as a result of their symptoms. If the MZDI score was <17 subjects were classified as 'normal' i.e. no increased risk of distress. If the MZDI score was between 17-33 and the MSPQ score <12 the subject was defined as being at risk of becoming distressed (Main et al. 1992). According to Main et al. (1992) subjects who score >33 on the MZDI

are classed as distressed depressive and individuals with an MZ score of 17-33 and MSPQ score >12 were classed as distressed somatic, however due to the small numbers of individuals identified in these subgroups, this group was combined for data analysis purposes as 'distressed'.

To score the IPAQ-SF, the level of activity (walking, moderate, vigorous) is combined with total number of minutes each activity was conducted for per day and the number of days over the previous week that the activity occurred. A defined formula (Appendix VI) can then be used to determine the number of MET-minutes/week, which is converted into high, medium or low activity levels using specific criteria (Appendix VI), with which to compare AEP, FP and healthy groups.

6.13Dependent Variables

Patient Reported Measures (Questionnaires)

Oswestry Disability Questionnaire
Visual Analogue Scale
Tampa Scale of Kinesiophobia
Distress Risk Assessment Method
STarT Back Screening Tool
International Physical Activity Questionnaire (Short-form)

Kinematics

Total Thoracic
Total Lumbar
Upper Thoracic
Lower Thoracic
Upper Lumbar
Lower Lumbar

→ Mean angle for each reference posture◆
→ Maximum flexion / extension angle for range of movement❖
→ Maximum flexion / extension angle (and subsequent midpoint) for each functional task*

Surface Electromyography

Right and Left sEMG for TrA/IO
Right and Left sEMG for EO
Right and Left sEMG for LM
Right and Left sEMG for LT

→ Normalised amplitude for each functional task*

Key: sEMG = surface electromyography, TrA/IO = Transversus Abdominis / Internal Oblique, External Oblique, LM = Lumbar Multifidus, LT = Longissimus Thoracis (Erector Spinae)

◆Postures: Usual Standing, Usual Sitting
❖Range of Movement: full trunk Flexion, full trunk Extension
*Functional Tasks: Box lift, Box replace, Reach up, Pen (bend to pick up), Pen (return to standing), sit-to-stand, stand-to-sit, step up, step down

Figure 20: Dependent variables for the main study statistical analysis

6.14 Statistical Considerations

6.14.1 Normality Testing and Homogeneity of Variance

In order to satisfy the assumptions for parametric testing data must be normally distributed and variances must be homogenous between groups (Field 2009; Portney and Watkins 2008). Before commencing statistical analysis, all study results were evaluated using the Shapiro-Wilk (S-W) test for normality. Significance for normality was set at $p<0.05$ with all analyses below this value assumed to be normally distributed, to support the use of a parametric test. Where a minority of variables within a data set reported S-W values which narrowly missed significance at the $p<0.05$ level, residual plots and histograms of unstandardized residuals for each variable were visually inspected as a secondary check for normality. If these appeared to be normally distributed, and the S-W test only narrowly missed significance, the variable was accepted as normally distributed. Full details are documented in Appendix VIII. For homogeneity of variance Levene's test was used. Any statistically significant results ($p<0.05$) obtained from this test indicate that the assumption of homogeneity of variances has been violated and the variances are not equal, thus the non-parametric statistical test would be chosen in this instance (Field 2009).

6.14.2 Power Calculation

Prior to data collection a sample size calculation was undertaken based on lower lumbar sagittal spinal angle, as a variable which has previously been shown to discriminate between AEP and FP sub-groups in sitting (Dankaerts et al. 2006c). The power calculation was based on the mean and standard deviation values for the lower lumbar sagittal spinal angle in usual sitting for the AEP, FP and healthy control groups and was obtained from the following data:

Mean value (standard deviation) AEP group = -18 (15)
Mean value (standard deviation) in FP group = 1 (22)
Mean value (standard deviation) in the healthy control group = -8 (17)

The values used to calculate the power calculation were obtained through visual identification of values reported in the article graphs (Dankaerts et al. 2006c) can therefore only be regarded to be accurate to the nearest whole number.

The effect size (A) was calculated as follows:
Common Standard Deviation (CSD) = (15 + 22 + 17)/3 = 18
Mean Difference (MD) = (1 – -18) + (1 – -8) (-8 – -18) / 3 = 12.666

Therefore the effect size (A) was calculated as the MD/CSD=0.70. A sample size of 24 subjects per group was calculated (in order to achieve a 95% confidence interval) based on the effect size of 0.70 and an α-level of 0.05, assuming a maximum power of 80% (Bratcher et al. 1970). Following statistical analysis, observed power was calculated in SPSS, as an output of the one-way ANOVA for each kinematic variable to ensure the power was sufficient for this study.

6.15 Statistical Analysis

All statistical analyses were conducted using SPSS. To ensure baseline subject characteristics were not confounding variables in the results, age, height, weight and BMI were evaluated between groups using one-way ANOVA and post hoc Bonferroni tests providing the requirements of parametric testing were achieved. Where these assumptions were not met the non-parametric Kruskal-Wallis test and post hoc Mann-Whitney U tests were used. Since gender comprises two categorical variables the Pearson's chi-square test (Field 2009; Fisher 1922; Pearson 1900) was used to evaluate differences in gender between groups.

Questionnaire data regarding prognostic screening (STarT Back), fear of movement (TSK), pain (VAS), risk of distress (DRAM) and disability (ODQ) was analysed using independent t-tests or the non-parametric equivalent (Mann-Whitney U Test) to establish between symptomatic group differences. Since the IPAQ-SF was completed by all participants (3 groups) a one-way ANOVA was used. Alternatively, if the assumptions were not met for the IPAQ-SF, the non-parametric equivalent test (Kruskal-Wallis) was to be used.

Visual inspection of normality Q-Q plots and histograms were used to ascertain skewness and kurtosis of the kinematic data. The S-W test was used to confirm normal distribution as this has been identified to be most appropriate for sample sizes less than 50, and provides greater power compared to the Kolmogorov-Smirnov test (Elliott and Woodward 2015; Steinskog et al. 2007). For all variables homogeneity of variance was established using Levene's test.

Since the existence of the two proposed classification sub-groups (AEP and FP) have been shown to be a real phenomena with regard to kinematics and muscle activity during static postures (Astfalck et al. 2010b; Dankaerts and O'Sullivan 2011; Dankaerts et al. 2006a, c; Dankaerts et al. 2009) no preliminary analysis comparing 'pooled' NSCLBP to healthy controls was deemed necessary. All kinematic and sEMG variables were continuous (interval/ ratio) data, therefore the descriptives are presented as the mean, standard deviation (SD) and 95% confidence intervals for the midpoint sagittal

spinal angles and mean normalised sEMG amplitudes respectively. For kinematic data one-way ANOVAs were used to determine between group kinematic differences. Post-hoc Bonferroni testing was then undertaken where significant differences were observed to determine pairwise differences between each of the three groups (AEP, FP, healthy control), as a key hypothesis of the study was to explore if sub-group differences exist and in which spinal regions these are observed. ANOVAs were repeated for the kinematic data with gender as a covariate to establish whether gender distribution between groups influenced the observed results.

Since the sEMG data did not follow a normal distribution non-parametric Kruskal-Wallis tests were used. Where differences ($p<0.05$) were observed Mann-Whitney U tests were conducted to establish pairwise differences between groups. Due to the risk of attaining type 1 errors using multiple Mann-Whitney U tests, a Bonferroni correction was applied (0.05 divided by the number of groups evaluated) and the post hoc significance level set to 0.0167 (Field 2009). A key aspect of the study is to understand if different MCI sub-groups of patients display different muscle activity levels throughout multiple functional tasks and how these groups differ, if at all, to a healthy control cohort.

Reliability results were reported for the within-day ICCs of the regional sagittal spinal angles, and normalised amplitude sEMG, across the 3 repeated trials for each functional task as understanding how consistently these patients perform each activity is essential to ensuring the methodology is robust and understanding whether consistency of functional movement and muscle activity is a defining factor for sub-groups of NSCLBP compared to healthy controls. The ICC, 95% confidence interval and standard error of measurement (square root of the mean square residual, produced via the ANOVA procedure in SPSS) for each midpoint regional sagittal spinal angle, or normalised amplitude muscle activity, during each functional task was calculated.

Intra-class correlation co-efficients (ICC) with 95% confidence intervals (CI) and SEMs were calculated in SPSS for the midpoint regional sagittal spinal angles and normalised amplitude muscle activity across the 3 trials for each task to ascertain within-subject reliability.

Within-subject reliability was assessed using a two-way mixed model (single measures) with consistency (Shrout and Fleiss 1979). In order to determine within-subject variation typical standard error of measurement between the three repeated trials was obtained by calculating of the square root of the "mean squared error", which is reported as an output of the one-way ANOVA (Batterham and George 2003; Hopkins 2000; Stratford and Goldsmith 1997). 95% Confidence intervals were also reported.

To interpret the relevance of the ICC 'reliability' level an ICC score of > 0.80 was considered 'excellent', > 0.61–0.80 'substantial', 0.40–0.60 'moderate' and < 0.40 'slight' (Landis and Koch 1977; Portney and Watkins 2008). This framework is consistent with other reliability studies reporting reliability of spinal posture during repeated testing (Sheeran et al. 2010)

6.15.1 Bonferroni Adjustment

Ordinarily for post-hoc Bonferroni testing a Bonferroni correction would need to be applied whereby, due to the multiple t-tests being performed on a single data set simultaneously an adjustment needs to be made to the p-values. This is usually performed by dividing the critical p value (α) by the number of comparisons being made. For example if alpha is set at 0.5 and 3 comparisons are being calculated the adjusted p-value would be 0.5/3 = 0.0167. For this study the Bonferroni post-hoc comparison procedures were performed in SPSS. Post-hoc Bonferroni testing in SPSS uses t-tests to perform pairwise comparisons between group means, but controls the overall error rate by setting the error rate for each test to the experiment-wise error rate divided by the total number of tests. Hence, the observed significance level is adjusted for the fact that multiple comparisons are being made. Therefore, in the interpretation of the results of the test, each comparison is considered significant when less than 0.05. It is to be noted that the Bonferroni adjustment is built into this procedure and no further calculation is necessary (IBM 2012). The technical notes for this procedure can be found in Appendix VII.

7 RESULTS

This chapter outlines the main study results. A summary of the statistical tests used for each outcome measure (based upon decision rules), subject characteristics, questionnaire results and an evaluation of the hierarchy of tasks (based on ROM) are presented. The kinematic and sEMG results will then be considered. For each of the kinematics and sEMG sections within-day reliability will be presented followed by the main study results for each parameter.

7.1 Statistical Analysis

Table 12 outlines the statistical test chosen for each variable in relation to the normal distribution of the results.

Table 12: Choice of statistical and post-hoc test based on normal distribution of data

	Between Group Differences (3 groups: AEP vs. FP vs. Healthy control)		Between Group Differences (2 groups: AEP vs. FP)	
Normal Distribution	Normally Distributed	Not Normally Distributed	Normally Distributed	Not Normally Distributed
Outcomes	Age Height Spinal Angles	Mass BMI IPAQ-SF Muscle Activity	VAS ODQ TSK STarT Back MSPQ	MZDI DRAM
Test and significance level	One-way ANOVA ($p<0.05$)	Independent Samples Kruskal-Wallis Test ($p<0.05$)	Independent t-test ($p<0.05$)	Mann-Whitney U Test ($p<0.05$)
Post-hoc Test	Bonferroni ($p<0.05$)	Mann-Whitney U ($p<0.0167$)	N/A	N/A

Key: FP = Flexion pattern motor control impairment, AEP = Active extension pattern motor control impairment, BMI = Body Mass Index (mass (kg)/height (m)^2), IPAQ-SF = International Physical Activity Questionnaire (Short Form), VAS = Visual Analogue Scale, ODQ = Oswestry Disability Questionnaire, TSK = Tampa Scale of Kinesiophobia, STarT Back = The STarT Back Tool, MSPQ = Modified Somatic Perceptions Questionnaire, MZDI = Modified Zung Depression Index, DRAM = Distress and Risk Assessment Method

7.2 Subject Demographics

A sample of 50 NSCLBP subjects (23 AEP, 27 FP) and 28 healthy control subjects were included in the final analysis for the study. One FP participant failed to complete and return the questionnaires therefore only 26 data sets were included for all FP questionnaire data. Table 13 presents the subject characteristics for the 3 groups evaluated in the study.

Table 13: Subject demographics across groups (active extension pattern, flexion pattern and control)

Variable		AEP (n=23)	FP (n=27)	Control (n=28)	Test Statistic / Significance
Gender Males Females		 4 (17.4%) 19 (82.6%)	 21 (77.8%) 6 (22.2%)	 12 (42.9%) 16 (57.1%)	X^2=0.487 df=2 p<0.001*
Age (years)		43.7 (11.2)	41.0 (10.0)	38.5 (11.2)	F=1.461 p=0.238
Mass (kg)		68.9 (18.0)	82.5 (14.6)	72.9 (15.2)	X^2=10.502 p=0.005* (AEP vs. FP: p=0.007*)
Height (cm)		164.9 (10.2)	175.9 (8.7)	169.4 (7.3)	F=10.100 p<0.001* (AEP vs. FP: p<0.001*, FP vs. Control: p=0.020*)
BMI (kg/m^2)		20.8 (4.9)	23.4 (3.5)	21.5 (4.1)	X^2=3.85 p=0.127
Site of Back Pain	Right	8 (34.8%)	5 (18.5%)	-	-
	Left	2 (8.7%)	3 (11.1%)		
	Central	13 (56.4%)	19 (70.4%)		

Key: FP = Flexion pattern motor control impairment, AEP = Active extension pattern motor control impairment, BMI = Body Mass Index (mass (kg)/height (m)^2), kg = kilogrammes, cm = centimetres, *significant difference for one way ANOVA / Independent Samples Kruskal-Wallis Test (p<0.05), for Bonferroni post hoc test (p<0.05), Mann-Whitney U (p<0.0167)

The chi-square test identified significant cohort gender differences in the proportion of males and females in each group. Although gender was fairly equally distributed in the healthy control group (42.9% males, 57.1% females), males comprised the greatest proportion of subjects in the FP group (77.8%) and conversely females comprised the majority of the AEP group (82.6%). No significant difference in age between groups was identified. The mean age of the participants is reflective of current CLBP population estimates reporting LBP to be most prevalent in the 35-44 age group (Health and Safety Executive 2014). Statistical analysis identified the FP group to be significantly taller than the AEP ($p<0.001$) and healthy control groups ($p=0.020$). Independent Samples Kruskal-Wallis Test identified significant differences in mass and BMI with the FP group being heavier compared to the AEP group, however post-hoc analysis revealed that the difference in BMI between these groups did not reach significance ($p=0.127$). The observed difference in gender demographics of the NSCLBP sub-groups may account for the differences observed with regard to height and mass, with males being assumed to be taller and heavier on average. However, due to BMI not reaching significance, BMI across groups appears to be comparable.

The location of reported back pain (between L1 and the buttock crease) was similar between groups with the majority of subjects in both groups reporting central symptoms (AEP 56.4%; FP 70.4%). A smaller percentage of individuals in both groups reported unilateral symptoms only. Table 14 shows the time since LBP onset for the AEP group and the FP group. The greatest proportion of FP individuals reported pain onset within the past 3-6 months (29.6%) whereas the AEP group had the greatest proportion of subjects experiencing pain onset within the previous 6-12 months (30.4%). For both groups a substantial proportion of individuals had experienced pain for more than 10 years (AEP 21.7%; FP 14.8%)

Table 14: Time since back pain onset (frequency and percentages) for the active extension pattern and flexion pattern groups

	Active Extension Pattern n=23		Flexion Pattern n=27	
	N	%	N	%
>3 months, ≤6 months	2	8.7	8	29.6
>6 months, ≤12 months	7	30.4	2	7.4
>1 year, ≤2 years	1	4.3	3	11.1
>2 years, ≤3 years	0	0	1	3.7
>3 years, ≤4 years	2	8.7	2	7.4
>4 years, ≤5 years	3	13	3	11.1
>5 years, ≤10 years	3	13	4	14.8
>10 years	5	21.7	4	14.8

The results for the IPAQ-SF scores are reported in Table 15.

Table 15: IPAQ-SF results for 3 groups (Active extension pattern, flexion pattern and healthy control) - frequencies defined by group and overall score

Variable		**AEP** (n=23)	**FP** (n=27)	**Healthy control** (n=28)	Test Statistic / Significance
IPAQ-SF (MET-min/week)	Low	6 (26.1%)	5 (19.2%)	7 (25.0%)	-
	Medium	8 (34.8%)	9 (34.6%)	7 (25.0%)	
	High	9 (39.1%)	12 (46.2%)	14 (50.0%)	
	Overall Score	4557.3 (6125.4)	4763.4 (5655.0)	2733.2 (2052.1)	p=0.666

Key: AEP = Active extension pattern motor control impairment, FP = Flexion pattern motor control impairment, IPAQ-SF = International Physical Activity Questionnaire (Short Form), MET-min/week = metabolic equivalent of task (MET) minutes per week

Similar frequencies of low, medium and high activity levels were reported on the IPAQ-SF across groups. Independent samples Kruskal-Wallis test for the overall scores of the IPAQ-SF revealed no significant between group differences, however, surprisingly, both the AEP and FP groups reported higher levels of activity (MET-min/week) compared to the healthy control group. These findings indicate that these groups are matched for activity level, thus minimising the impact of differing activity levels as a potential confounding variable.

7.3 Patient Reported Measures

7.3.1 Questionnaires

Table 16: Patient reported measure results for the active extension pattern and flexion pattern groups

Patient Reported Measure		AEP (n=23)	FP (n=26)	Test Statistic / Significance
ODQ		22.5 (11.6)	21.6 (10.0)	t=0.290 p=0.773
STarT Back		3.4 (2.2)	3.3 (2.1)	t=0.210 p=0.834
DRAM	MSPQ	6.4 (3.9)	5.0 (4.4)	t=1.096 p=0.279
	MZDI	23.4 (10.8)	17.7 (8.6)	t=-1.865 p=0.062
	Overall Score	29.8 (12.5)	22.7 (10.9)	t=-2.211 p=0.027*
VAS		4.6 (1.4)	4.5 (1.4)	t=0.018 p=0.986
TSK		37.5 (6.8)	37.6 (5.3)	t=-0.008 p=0.993

Key: AEP = Active extension pattern motor control impairment, FP = Flexion pattern motor control impairment, ODQ = Oswestry Disability Questionnaire, STarT Back = The STarT Back Tool, MSPQ = Modified Somatic Perceptions Questionnaire, MZDI = Modified Zung Depression Index, DRAM = Distress and Risk assessment method, VAS = Visual Analogue Scale, TSK = Tampa Scale of Kinesiophobia

Independent t-tests for the ODQ, VAS, TSK and STarT Back revealed no significant differences in overall score between the AEP and FP groups. No significant differences between groups for the individual MSPQ or MZDI questionnaires were also identified, indicating that when considered in isolation no between groups differences in depression or somatic perception are observed. However, when these questionnaires were combined (as per the DRAM protocol) a significant between groups difference was observed with the AEP group displaying an overall significantly more distressed profile compared to the FP group (29.8 compared to 22.7 respectively, p=0.027).

As well as observing individual scores, grouped scores for each of the patient reported measures were also calculated, the results of which are displayed in Table 17 below. For the DRAM, Main et al.

(1992) suggest the scores be grouped as 'Normal' (Modified Zung score <17), 'At Risk' (Modified Zung 17-33 and MSPQ <12), 'Distressed Somatic' (Modified Zung 17-33 and MSPQ >12) and 'Distressed Depressive' (Modified Zung >33). As the data is categorical with more than two groups log-linear analysis was to be used (Field 2009). During analysis some data for the sub-grouped distressed measures did not satisfy the test assumption that all expected frequencies must be greater than 1, due to the small number of subjects achieving this score. Thus the distressed depressive and distressed somatic groups were pooled for analysis (Hobby et al. 2001).

Table 17: Grouped score results of patient reported measures for the active extension pattern and flexion pattern groups

Patient Reported Measure		AEP (n=23)	FP (n=26)	Test Statistic / Significance
ODQ	Minimal	13 (56.5%)	14 (53.8%)	N/A
	Moderate	8 (34.8%)	11(42.3%)	
	Severe	2 (8.7%)	1(3.8%)	
STarT Back	Low	13 (56.5%)	13 (50.0%)	N/A
	Medium	4 (17.4%)	9 (34.6%)	
	High	6 (26.1%)	4 (15.4%)	
DRAM	Normal	6 (26.1%)	11 (42.3%)	N/A
	At Risk	11 (47.8%)	12 (46.2%)	
	Distressed	6 (26.1%)	3 (11.5%)	
VAS	Mild	11 (47.8%)	12 (46.2%)	X^2=0.014 p=0.907
	Moderate	12 (52.2%)	14 (53.8%)	
	Severe	0 (0%)	0 (0%)	
TSK	Low	10 (43.5%)	9 (34.6%)	X^2=0.404 p=0.569
	High	13 (56.5%)	17 (65.4%)	

Key: AEP = Active extension pattern motor control impairment, FP = Flexion pattern motor control impairment, ODQ = Oswestry Disability Questionnaire, STarT Back = The STarT Back Tool, MSPQ = Modified Somatic Perceptions Questionnaire, MZDI = Modified Zung Depression Index, DRAM = Distress and Risk assessment method, VAS = Visual Analogue Scale, TSK = Tampa Scale of Kinesiophobia, df = degrees of freedom

The Pearson's Chi-Square test evaluated group scores for the TSK and VAS and no significant between group differences were identified in either measure. The DRAM, STarT Back and ODQ are sub-divided into 3 potential categories thus inferential statistics required would be log-linear analysis (Field 2009). An assumption of using log-linear analysis is that less than 20% of cells must have an expected value of 5 or less and all cells must have frequencies greater than 1. The ODQ and STarT

Back results do not meet these assumptions therefore these cannot be robustly evaluated using this method. For this reason no inferential analysis was conducted and results are interpreted on percentages alone. Between group results for ODQ show similar percentages and frequencies in each category, thus suggesting the AEP and FP groups demonstrate similar levels of reported disability, with the majority of subjects reporting minimal to moderate disability and a minority of individuals in each group (2 AEP, 1 FP) reporting severe disability. The STarT Back tool showed similar frequencies of subjects identified as being at low risk of poor prognosis. However of the remaining individuals in the AEP group appeared to have a higher proportion of high risk patients compared to the FP group (AEP: n=6, 26.1%; FP: n=4, 15.4%). Conversely a higher proportion of the FP group were classified as medium risk compared to the AEP group (FP: n=9, 34.6%; AEP: n=4, 17.4%). However, due to the small frequencies in each risk category these results must be viewed with caution.

The categorical DRAM data could not be analysed using log-linear analysis due to the test assumptions not being met as not all cells have expected values >1 (Field 2009). However, visual inspection of the observed frequencies for the DRAM patient-reported measure demonstrated that in the FP group the majority of subjects (88.5%) were identified to be either 'normal' or 'at risk' of distress. Whereas in the AEP group, these proportions were more evenly distributed with 26.1% observed as being normal, 47.8% 'at risk' and 26.1% 'distressed'. When considered in conjunction with the significant difference in mean scores (Table 16), it appears that the AEP group may have a higher percentage of individuals presenting with high levels of distress compared to the FP group, however further investigation of this measure in larger populations is warranted.

In summary, the patient reported measures demonstrate overall that the NSCLBP sub-groups were well matched for pain severity, fear of movement, bothersomeness, risk of poor prognosis and disability. The DRAM scores suggest that there may be a slight increase in distress levels in the AEP group compared to the FP group.

7.3.2 Verbally Reported Pain

Table 18: Verbally reported pain scores (mean and standard deviation) for maximum pain experienced during each posture, range of movement and functional task (active extension pattern and flexion pattern) during data collection

Posture / Task	AEP	FP
Usual standing	1.4 (1.6)	1.8 (1.8)
Flexion	2.2 (2.0)	3.0 (2.1)
Extension	2.4 (1.7)	3.3 (2.6)
Usual Sitting	1.5 (1.3)	1.8 (1.6)
Sit-to-stand-to-sit	1.7 (1.7)	2.2 (1.8)
Box rotation	1.7 (1.4)	2.3 (2.0)
Reach Up	1.3 (1.3)	1.7 (1.4)
Step up and down	1.4 (1.3)	1.6 (1.4)
Bend and return from picking up pen	1.8 (1.5)	2.5 (2.2)

Key: AEP = Active extension pattern motor control impairment, FP = Flexion pattern motor control impairment

Table 18 outlines the mean (and SD) scores for the verbally reported pain scores recorded following each activity during data collection. All values are less than 3.3 indicating overall mild pain on average between tasks (Jensen et al. 2003). Full flexion and extension ROM both scored most highly for pain in both the AEP and FP groups. Interestingly pain scores during extension ROM were higher in the FP group compared to the AEP group (3.3 compared to 2.4 respectively). Bending and returning from picking up a pen both also scored high with regard to pain for the FP group (2.5) and to a lesser extent the AEP group (1.8) compared with other activities.

7.4 Spinal Kinematics

In this section the results of the kinematics will be presented. The results have been split by activity, with the posture results presented first (usual standing and usual sitting), followed by full ROM (flexion, extension), and finally the functional tasks (step down, step up, reach up, pick up pen (bend down), pick up pen (return), stand-to-sit, sit-to-stand, box replace and box lift).

The results for each activity will be structured as follows:

- Subject characteristics, statistical analysis, post-hoc testing and hypothesis testing across the three groups (AEP, FP and healthy control).
- Graphical representation of results:
    - Postures and ROM results are displayed as error bars with 95% confidence intervals for each regional sagittal spinal midpoint angle across the three groups
    - Tasks results are displayed as 'Max-midpoint-min' (High-low) graphs to depict the mean midpoint and the mean maximum flexion and extension regional sagittal spinal angle across the three groups
- Brief descriptive overview of the results.

Analyses within each of these 'task' sub-sections will first present the results for the total spinal segments (total thoracic and total lumbar), followed by the results for the sub-spinal segments (upper thoracic, lower thoracic, upper lumbar, lower lumbar). AEP, FP and healthy controls will be referred to as 'AEP group', 'FP group' and 'healthy control group' throughout for consistency. In the descriptive overview of the results significant results will be discussed first. For ease of use, the results will be discussed with relation to FP position in comparison the AEP (e.g. 'the FP group operate in greater flexion compared to the AEP group'), FP group position in comparison to the healthy control group, and finally the AEP group position in comparison to the healthy control group.

Missing Data

For some trials a smaller sample has been included in the final analysis due to calculation error and poor data quality. Due to an error in the calculation of the lower lumbar and upper lumbar spine angle during full flexion a number of data sets were omitted from the final analysis in these spinal regions. Similarly this phenomenon occurred to a lesser extent during the pen pick up task, with 1 FP data set omitted for the lower lumbar spine and 2 FP data sets omitted for the upper lumbar spine. During the extension tasks, as well as omitted data from the upper and lower lumbar spinal regions, 3 AEP subjects displayed calculation errors in the total lumbar spine angles and thus were subsequently removed from the final analysis. Additionally, 1 FP subject from the box task, 1 AEP subject from the sit-to-stand/stand-to-sit tasks and 2 AEP subjects from the pen pick up tasks were omitted from the final analysis due to poor data quality. The final number of subjects included in each group analysis are highlighted in the descriptives tables for each activity.

Outliers

Scatter plots for each variable were produced to identify outliers and the raw data re-checked (and re-processed if applicable) in Vicon® to ensure any potential outliers were due to alterations in movement behaviour rather than data errors. Due to the rigorous data checking procedures, all remaining errors were considered to be as a result of different movement behaviours and therefore no outliers were removed from the final analysis

7.4.1 Kinematics – Within-Day Reliability

Table 19: Within-day reliability for total sagittal spinal angles during functional tasks

		Total Thoracic		Total Lumbar	
		ICC (95% CI)	SEM	ICC (95% CI)	SEM
Step Down	AEP	0.799 (0.646 to 0.901)	4.4	0.727 (0.538 to 0.862)	5.4
	FP	0.748 (0.585 to 0.865)	4.2	0.867 (0.766 to 0.932)	5.3
	Control	0.802 (0.668 to 0.895)	4.2	0.774 (0.626 to 0.879)	6.5
Step Up	AEP	0.787 (0.627 to 0.895)	4.7	0.798 (0.643 to 0.900)	4.7
	FP	0.634 (0.431 to 0.796)	5.1	0.839 (0.721 to 0.917)	6
	Control	0.839 (0.724 to 0.916)	3.8	0.776 (0.629 to 0.880)	6.4
Reach Up	AEP	0.579 (0.343 to 0.773)	7.9	0.741 (0.559 to 0.870)	5
	FP	0.685 (0.498 to 0.828)	5.1	0.874 (0.777 to 0.935)	4.8
	Control	0.666 (0.476 to 0.814)	5.5	0.816 (0.688 to 0.903)	5.1
Pick up pen (Bend Down)	AEP	0.610 (0.369 to 0.800)	7.5	0.652 (0.423 to 0.825)	6.1
	FP	0.718 (0.535 to 0.852)	4.2	0.830 (0.701 to 0.914)	5.7
	Control	0.727 (0.559 to 0.851)	4.6	0.874 (0.781 to 0.935)	4.2
Pick up pen (Return)	AEP	0.613 (0.372 to 0.802)	7.9	0.706 (0.498 to 0.8560	5.8
	FP	0.788 (0.637 to 0.892)	3.8	0.857 (0.744 to 0.928)	5.1
	Control	0.726 (0.557 to 0.850)	4.9	0.855 (0.750 to 0.924)	4.4
Stand-to-Sit	AEP	0.754 (0.572 to 0.879)	5.2	0.693 (0.484 to 0.845)	5.9
	FP	0.567 (0.348 to 0.752)	5.5	0.828 (0.704 to 0.911)	6
	Control	0.808 (0.677 to 0.898)	4	0.800 (0.664 to 0.893)	6
Sit-to-Stand	AEP	0.653 (0.430 to 0.822)	6.9	0.574 (0.330 to 0.774)	7.2
	FP	0.550 (0.328 to 0.741)	6.2	0.775 (0.623 to 0.881)	7
	Control	0.756 (0.600 to 0.868)	4.7	0.830 (0.710 to 0.911)	5.5
Box Replace	AEP	0.781 (0.618 to 0.891)	5.2	0.758 (0.584 to 0.879)	5.2
	FP	0.578 (0.356 to 0.762)	5.7	0.878 (0.782 to 0.939)	5.3
	Control	0.810 (0.680 to 0.900)	4.1	0.764 (0.611 to 0.873)	6.9
Box Lift	AEP	0.616 (0.389 to 0.797)	7.1	0.726 (0.537 to 0.861)	6.1
	FP	0.506 (0.273 to 0.714)	6.3	0.846 (0.729 to 0.922)	6.2
	Control	0.821 (0.697 to 0.906)	3.9	0.744 (0.583 to 0.861)	6.8

Key: ICC = Interclass Correlation Coefficient, CI = Confidence Interval, SEM = Standard Error of Measurement (degrees)

Table 20: Within-day reliability for the thoracic regional sagittal spinal angles during functional tasks

		Upper Thoracic		Lower Thoracic	
		ICC (95% CI)	SEM	ICC (95% CI)	SEM
Step Down	AEP	0.720 (0.528 to 0.858)	4.4	0.906 (0.823 to 0.956)	3.8
	FP	0.739 (0.572 to 0.860)	4	0.864 (0.762 to 0.930)	3.4
	Control	0.805 (0.672 to 0.896)	3.3	0.880 (0.791 to 0.938)	3.8
Step Up	AEP	0.720 (0.527 to 0.858)	4.6	0.887 (0.791 to 0.946)	4.2
	FP	0.649 (0.450 to 0.805)	4.5	0.828 (0.705 to 0.911)	3.7
	Control	0.850 (0.742 to 0.922)	2.9	0.888 (0.803 to 0.942)	3.6
Reach Up	AEP	0.523 (0.276 to 0.737)	7	0.790 (0.631 to 0.896)	5.2
	FP	0.675 (0.485 to 0.822)	4.3	0.726 (0.553 to 0.852)	4.2
	Control	0.663 (0.472 to 0.811)	4.6	0.812 (0.683 to 0.901)	4.4
Pick up pen (Bend Down)	AEP	0.509 (0.248 to 0.737)	7.1	0.776 (0.601 to 0.893)	5.5
	FP	0.676 (0.477 to 0.827)	4.1	0.795 (0.647 to 0.895)	3.6
	Control	0.762 (0.608 to 0.871)	3.8	0.873 (0.778 to 0.934)	3.4
Pick up pen (Return)	AEP	0.450 (0.182 to 0.697)	7.9	0.742 (0.549 to 0.875)	5.5
	FP	0.657 (0.452 to 0.816)	4	0.772 (0.613 to 0.883)	3.8
	Control	0.701 (0.523 to 0.835)	4.6	0.842 (0.728 to 0.917)	3.8
Stand-to-Sit	AEP	0.693 (0.484 to 0.845)	5.1	0.804 (0.648 to 0.905)	5.1
	FP	0.615 (0.407 to 0.784)	5.1	0.781 (0.633 to 0.884)	3.8
	Control	0.788 (0.647 to 0.887)	3.7	0.881 (0.791 to 0.938)	3.5
Sit-to-Stand	AEP	0.572 (0.327 to 0.773)	6.6	0.778 (0.609 to 0.892)	5
	FP	0.560 (0.339 to 0.747)	5.5	0.780 (0.632 to 0.884)	3.8
	Control	0.670 (0.481 to 0.816)	5	0.838 (0.722 to 0.915)	4.1
Box Replace	AEP	0.782 (0.619 to 0.892)	4.2	0.881 (0.780 to 0.943)	4
	FP	0.655 (0.454 to 0.812)	4.6	0.852 (0.739 to 0.925)	3.4
	Control	0.828 (0.707 to 0.910)	3.2	0.841 (0.728 to 0.917)	4.5
Box Lift	AEP	0.648 (0.430 to 0.816)	5.4	0.773 (0.605 to 0.887)	5.6
	FP	0.449 (0.210 to 0.673)	5.6	0.759 (0.598 to 0.874)	4.2
	Control	0.801 (0.667 to 0.895)	3.6	0.860 (0.757 to 0.927)	4.1

Key: ICC = Interclass Correlation Coefficient, CI = Confidence Interval, SEM = Standard Error of Measurement (degrees)

Table 21: Within-day reliability for the lumbar regional sagittal spinal angles during functional tasks

		Upper Lumbar		Lower Lumbar	
		ICC (95% CI)	SEM	ICC (95% CI)	SEM
Step Down	AEP	0.858 (0.741 to 0.932)	4.2	0.855 (0.736 to 0.930)	7.2
	FP	0.861 (0.756 to 0.928)	3.5	0.846 (0.732 to 0.920)	6
	Control	0.828 (0.707 to 0.910)	3.3	0.736 (0.571 to 0.856)	6
Step Up	AEP	0.851 (0.729 to 0.928)	4.1	0.924 (0.855 to 0.964)	5.3
	FP	0.788 (0.644 to 0.889)	4.3	0.811 (0.677 to 0.901)	6.9
	Control	0.798 (0.661 to 0.892)	3.6	0.715 (0.541 to 0.843)	5.9
Reach Up	AEP	0.640 (0.420 to 0.811)	5.8	0.784 (0.622 to 0.893)	7.8
	FP	0.679 (0.489 to 0.824)	4.6	0.600 (0.388 to 0.773)	10.5
	Control	0.582 (0.370 to 0.759)	4.7	0.715 (0.542 to 0.844)	5.2
Pick up pen (Bend Down)	AEP	0.782 (0.610 to 0.896)	4.7	0.869 (0.751 to 0.940)	6.9
	FP	0.855 (0.742 to 0.928)	3.3	0.777 (0.620 to 0.886)	7.1
	Control	0.767 (0.616 to 0.875)	3.5	0.697 (0.518 to 0.833)	5.7
Pick up pen (Return)	AEP	0.720 (0.517 to 0.863)	4.8	0.810 (0.654 to 0.911)	7.7
	FP	0.848 (0.731 to 0.924)	3.4	0.790 (0.639 to 0.893)	7
	Control	0.751 (0.593 to 0.865)	3.5	0.726 (0.558 to 0.850)	5.4
Stand-to-Sit	AEP	0.668 (0.450 to 0.831)	6.1	0.839 (0.706 to 0.924)	7.1
	FP	0.712 (0.534 to 0.844)	4.7	0.702 (0.521 to 0.838)	8.7
	Control	0.497 (0.271 to 0.700)	6.2	0.533 (0.313 to 0.726)	8.8
Sit-to-Stand	AEP	0.641 (0.414 to 0.815)	6.2	0.749 (0.565 to 0.876)	8.4
	FP	0.789 (0.644 to 0.889)	4.1	0.669 (0.476 to 0.818)	9.9
	Control	0.495 (0.269 to 0.698)	5.9	0.589 (0.379 to 0.764)	8.2
Box Replace	AEP	0.796 (0.641 to 0.900)	5	0.869 (0.758 to 0.937)	6.4
	FP	0.825 (0.697 to 0.910)	3.9	0.797 (0.654 to 0.895)	6.7
	Control	0.778 (0.632 to 0.881)	3.6	0.737 (0.572 to 0.857)	5.9
Box Lift	AEP	0.760 (0.586 to 0.880)	5.1	0.856 (0.737 to 0.931)	6.7
	FP	0.790 (0.643 to 0.891)	4.2	0.810 (0.674 to 0.902)	6.9
	Control	0.758 (0.603 to 0.869)	4	0.628 (0.428 to 0.789)	6.8

Key: ICC = Interclass Correlation Coefficient, CI = Confidence Interval, SEM = Standard Error of Measurement (degrees)

Regional sagittal spinal angles (across all tasks) showed moderate to excellent test re-test reliability (ICC 0.449 to 0.924), with the overall standard error of measurement falling between 2.9 to 10.5 degrees. When split by group, the results remain consistent with all three groups demonstrating moderate to excellent ICC scores (AEP: 0.450 to 0.924, FP: 0.449 to 0.878, and healthy control: 0.495 to 0.888). Similarly, the SEM (degrees) results are consistent for each group across all tasks, with 3.8 to 8.4, 3.3 to 10.5 and 2.9 to 8.8, for the AEP, FP and healthy control groups respectively. These results demonstrate that regardless of the task in question, all groups performed each task consistently throughout all spinal regions across three trials. These results support the main study methods that by establishing the midpoint angle across three trials to calculate an overall mean 'midpoint' for each task and region will provide a true reflection of the subjects' movement pattern.

7.4.2 Kinematics – Postures

Tables 22 and 23 detail the descriptive and inferential statistics, post-hoc tests and hypothesis testing for usual standing and usual sitting posture. Mean sagittal spinal angle, standard deviation and 95% confidence intervals for each spinal region are reported in degrees for all three groups. Results of the one-way ANOVA (F-statistic, p-value) ($p<0.05$) and post-hoc Bonferroni test ($p<0.05$) are stated and significant findings marked with an asterisk (*). Additionally, null hypothesis 1 is rejected or not rejected.

Figures 21 and 22 present the mean angle and 95% confidence intervals across the three groups (AEP, FP, healthy control) for each spinal segment during usual standing posture (Figure 21) and usual sitting posture (Figure 22). Positive values (above zero) indicate flexion and negative values (below zero) indicate extension. A red dashed line indicates where significant differences ($p<0.05$) between groups have been observed. A grey dashed line indicates a general trend ($p<0.1$).

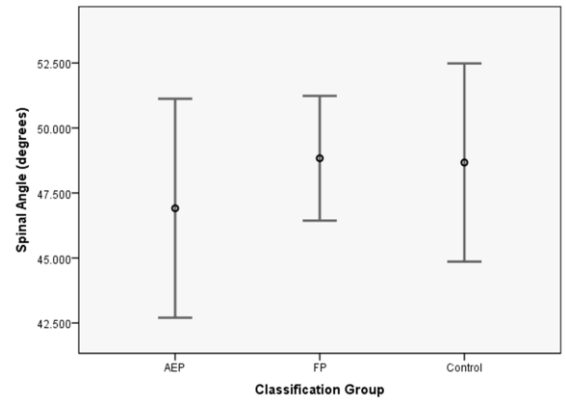
7.4.2.1 Usual Standing

Table 22: Descriptive and inferential statistics, post-hoc testing for usual standing between the active extension pattern, flexion pattern and control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23	FP n=27	Healthy control n=28	F	p		
Usual Standing	Total Thoracic	47.0 (9.7) (43.3 to 50.5)	48.8 (6.1) (45.4 to 51.9)	48.7 (9.8) (45.4 to 51.9)	0.367	0.694	-	NR
	Total Lumbar	-39.3 (11.5) (-45.3 to -33.2)	-33.6 (16.7) (-39.2 to -28.0)	-36.1 (14.6) (-41.6 to -30.6)	0.938	0.396	-	NR
	Upper Thoracic	32.6 (7.8) (29.9 to 35.4)	31.6 (4.1) (29.1 to 34.2)	32.9 (7.6) (30.4 to 35.4)	0.275	0.761	-	NR
	Lower Thoracic	9.4 (12.6) (4.8 to 14.0)	17.0 (10.0) (12.7 to 21.3)	11.5 (11.1) (7.3 to 15.7)	3.135	0.049*	AEP vs. FP: 0.058 AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.221	NR
	Upper Lumbar	-18.0 (12.1) (-22.2 to -13.7)	-8.1 (9.8) (-12.0 to -4.2)	-15.8 (8.7) (-19.6 to -12.0)	6.691	0.002*	AEP vs. FP: 0.003* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.020*	R
	Lower Lumbar	-25.1 (21.1) (-32.6 to -17.7)	-31.0 (17.5) (-37.8 to -24.1)	-24.2 (15.0) (-31.0 to -17.5)	1.128	0.329	-	NR

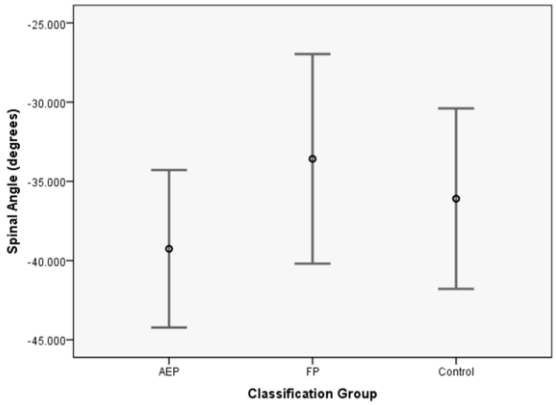
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine in usual standing



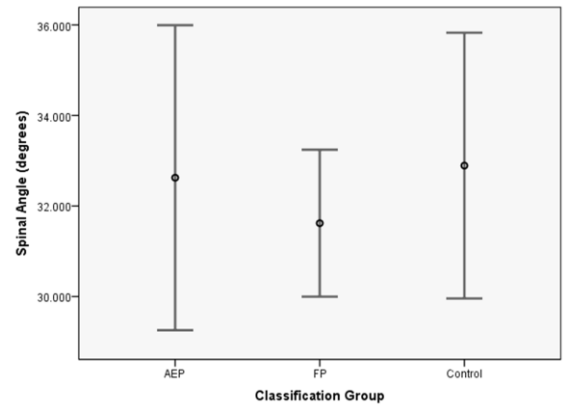
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine in usual standing



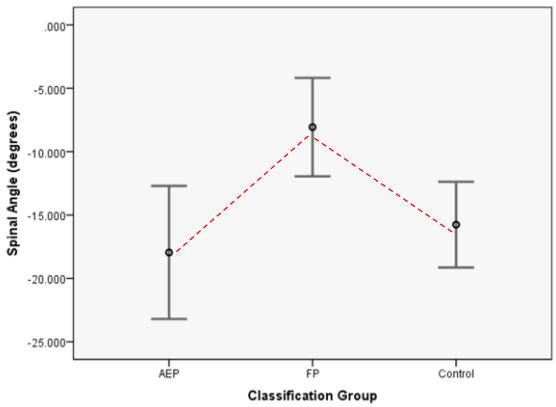
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine in usual standing



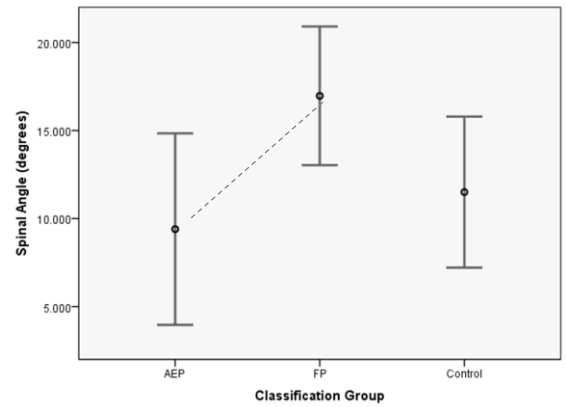
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine in usual standing



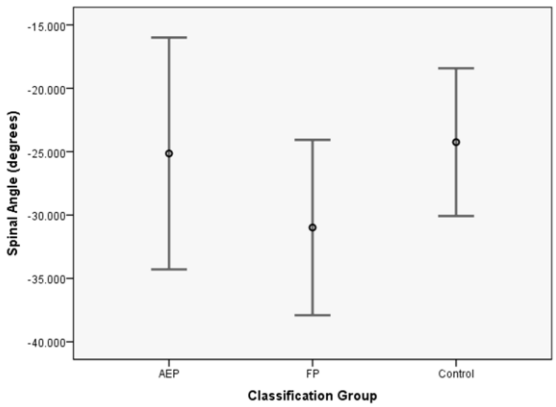
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine in usual standing



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine in usual standing



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 21: Usual Standing: 95% confidence intervals (error bars) for active extension pattern, flexion pattern and healthy control groups across six spinal segments

Total Spinal Angles – Usual Standing

No significant between groups differences in spinal angle were observed in the total thoracic and total lumbar spinal regions. Although AEP subjects were observed to adopt more extended standing postures in both the total thoracic and total lumbar regions, compared to the FP and healthy controls, one-way ANOVA revealed no significant between group differences.

Regional Spinal Angles – Usual Standing

Significant differences were noted between the AEP and FP groups in the upper lumbar spine ($p=0.003$), with the FP group adopting a more flexed standing posture in this spinal region compared to the AEP group. Significant differences were also observed between the FP and healthy control groups ($p=0.020$), with the FP group adopting more flexed postures compared to the healthy control group. No differences in sagittal spinal angle in the upper thoracic, lower thoracic or lower lumbar regions were observed between groups, however a similar pattern of movement between the AEP and FP groups was observed in the lower thoracic spine, with the FP group appearing to adopt a more flexed standing position compared to the AEP group in this spinal region ($p=0.058$), although significance was not reached ($p>0.05$). No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

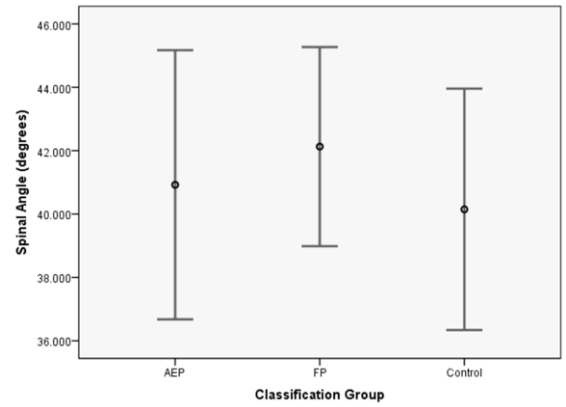
7.4.2.2 Usual Sitting

Table 23: Descriptive and inferential statistics, post-hoc testing for usual sitting between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23	FP n=27	Healthy control n=28	F	p		
Usual Sitting	Total Thoracic	40.9 (9.8) (37.1 to 44.8)	42.1 (7.9) (38.6 to 45.7)	40.1 (9.8) (36.7 to 43.6)	0.321	0.727	-	NR
	Total Lumbar	-19.4 (12.9) (-26.2 to -12.6)	-3.6 (16.9) (-9.8 to 2.7)	-12.2 (18.1) (-18.3 to -6.1)	5.908	0.004*	AEP vs. FP: 0.003* AEP vs. Healthy control: 0.365 FP vs. Healthy control: 0.160	R
	Upper Thoracic	27.4 (8.9) (24.1 to 30.7)	23.3 (6.2) (20.2 to 26.3)	26.9 (6.2) (23.9 to 29.9)	2.069	0.133	-	NR
	Lower Thoracic	11.9 (12.2) (7.3 to 16.5)	23.6 (8.3) (19.3 to 27.8)	12.3 (12.3) (8.1 to 16.5)	9.485	<0.001*	AEP vs. FP: 0.001* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.001*	R
	Upper Lumbar	-5.9 (9.4) (-9.6 to -2.2)	6.4 (9.2) (3.0 to 9.8)	-0.5 (8.4) (-3.9 to 2.8)	11.959	<0.001*	AEP vs. FP: <0.001* AEP vs. Healthy control: 0.110 FP vs. Healthy control: 0.015*	R
	Lower Lumbar	-13.0 (19.2) (-19.5 to -6.5)	-10.4 (13.8) (-16.4 to -4.4)	-10.7 (14.1) (-16.6 to -4.8)	0.197	0.821	-	NR

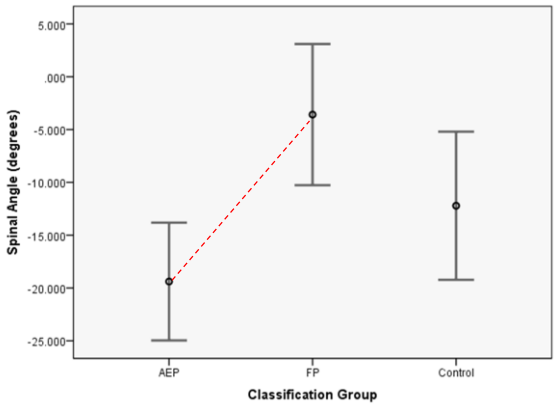
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine in usual sitting



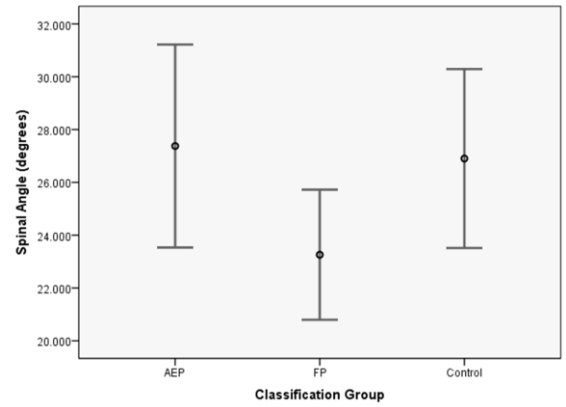
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine in usual sitting



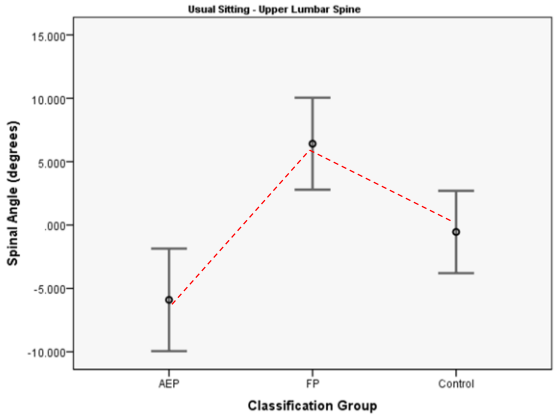
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine in usual sitting



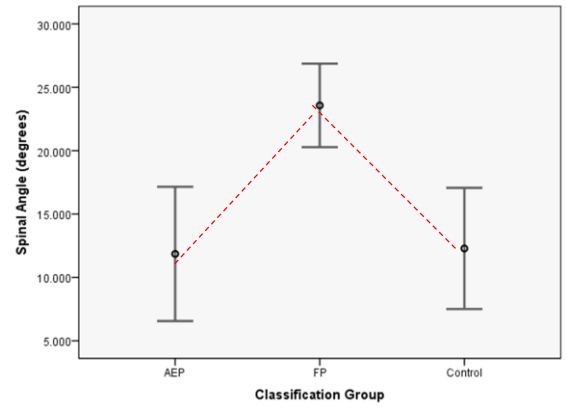
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine in usual sitting



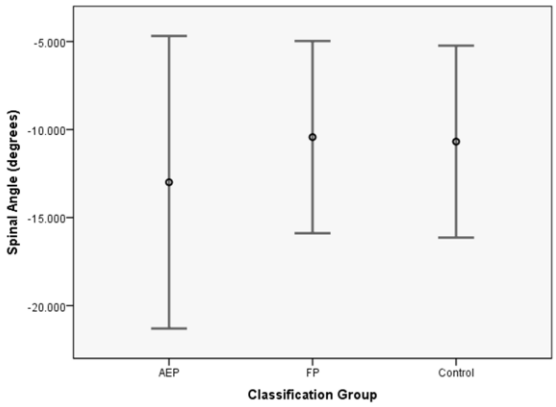
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine in usual sitting



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine in usual sitting



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 22: Usual Sitting: 95% confidence intervals (error bars) for the active extension pattern, flexion pattern and healthy control groups across six spinal segments

Total Spinal Angles – Usual Sitting

The FP group adopted a significantly more flexed total lumbar angle compared to the AEP group during usual sitting. The healthy control group appear to have adopted a total lumbar spinal angle in sitting which lies between the mean ROM for the FP and AEP groups, however no significant differences between the NSCLBP groups and the healthy control group were observed. No significant between groups differences in spinal angle were observed in the total thoracic spine.

Regional Spinal Angles – Usual Sitting

Significant differences were noted between the AEP and FP groups in the upper lumbar ($p<0.001$) and lower thoracic spine ($p=0.001$), with the FP group adopting sitting postures in greater flexion compared to the AEP group. Significant differences were also observed between the FP and healthy control groups in the upper lumbar ($p=0.015$) and lower thoracic spine ($p=0.001$) with the FP group again adopting more flexed postures compared to the healthy control group. Additionally, in the upper lumbar region the AEP group appeared to adopt more extended sitting postures when compared to the healthy control group, however this difference did not reach significance ($p=0.110$). In the lower thoracic region, the AEP and healthy control groups appeared to adopt similar mean spinal ROM, with both groups observed to be significantly more extended in these regions compared to the FP group. No significant differences in spinal angle in the upper thoracic or lower lumbar spine were observed between groups. No significant between groups differences in AEP and healthy control groups were observed in any total or regional spinal segment.

7.4.2.3 Postures: Significant Findings

For usual standing and usual sitting postures significant differences were only observed in the total lumbar spine during usual sitting ($p=0.003$) with the FP group operating in greater flexion compared to the AEP group. No differences in the total thoracic spine were observed in any postural task.

In standing the only significant differences were observed in the upper lumbar region between the AEP and FP subgroups, and healthy control and FP subgroups with the FP group adopting postures in this region which were significantly more flexed compared to both the AEP and healthy control groups. In sitting postural differences were observed in both the upper lumbar (AEP vs. FP, FP vs. healthy control) and lower thoracic (AEP vs. FP, FP vs. healthy control) spinal regions with the FP groups adopting more flexed postures in these spinal regions compared with the other groups.

For both postural tasks the null hypothesis was not rejected for the total thoracic, upper thoracic and lower lumbar regions that there is no difference in sagittal spinal angles between MCI subgroups of NSCLBP subjects and healthy controls. In usual standing the null hypothesis was accepted for the total lumbar and lower thoracic spine.

However the null hypothesis was rejected in the upper lumbar spine during both usual standing and usual sitting to accept that differences in sagittal spinal angles between MCI subgroups of NSCLBP were present during postural tasks. Additionally, during usual sitting the null hypothesis that no differences in sagittal spinal angles between MCI subgroups of NSCLBP are present was rejected for the total lumbar and lower thoracic spinal regions. The null hypothesis was not rejected for all spinal regions across both postural tasks with regard to differences between the healthy control group and NSCLBP subgroups, with the exception of the lower thoracic spine (FP vs. healthy control).

7.4.3 Kinematics – Range of Movement

Tables 24 and 25 detail the descriptive and inferential statistics, post-hoc tests and hypothesis testing for full spinal flexion and full spinal extension range of movement. Mean sagittal spinal angle, standard deviation and 95% confidence intervals for each spinal region are reported in degrees for all three groups. Results of the one-way ANOVA (F-statistic, p-value) and post-hoc Bonferroni test ($p<0.05$) are stated and significant findings marked with an asterisk (*). Additionally, null hypothesis 2 is accepted or rejected.

Figures 23 and 24 present the mean maximum flexion angle and 95% confidence intervals across the three groups (AEP, FP, healthy control) for each spinal segment during full flexion (Figure 23) and full extension (Figure 24). Positive values (above zero) indicate flexion and negative values (below zero) indicate extension. A red dashed line indicates where significant differences ($p<0.05$) between groups have been observed. A grey dashed line indicates a general trend ($p<0.1$).

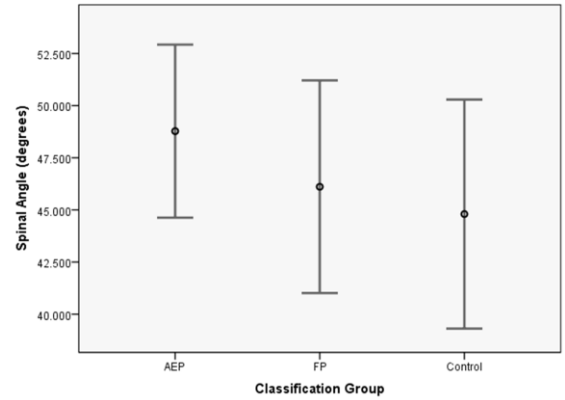
7.4.3.1 Flexion

Table 24: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for flexion between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23†	FP n=27‡	Healthy control n=28 ł	F	p		
Flexion	Total Thoracic	48.8 (9.6) (43.6 to 54.0)	46.1 (12.9) (41.3 to 50.9)	44.8 (14.2) (40.1 to 49.5)	0.650	0.525	-	NR
	Total Lumbar	1.3 (9.7) (-2.9 to 5.6)	10.0 (11.1) (6.1 to 13.9)	8.0 (9.8) (4.2 to 11.9)	4.806	0.011*	AEP vs. FP: 0.011* AEP vs. Healthy control: 0.069 FP vs. Healthy control: 1.000	R
	Upper Thoracic	26.8 (9.4) (22.0 to 31.6)	22.9 (10.8) (18.5 to 27.3)	22.5 (13.6) (18.2 to 26.9)	1.021	0.365	-	NR
	Lower Thoracic	25.2 (8.0) (22.3 to 28.0)	29.8 (5.7) (27.1 to 32.4)	26.8 (7.0) (24.3 to 29.5)	2.885	0.062	-	NR
	Upper Lumbar	-1.9 (10.2) (-5.9 to 2.0)	9.0 (6.5) (5.2 to 12.8)	3.4 (5.9) (-0.1 to 6.9)	8.043	0.001*	AEP vs. FP: 0.001* AEP vs. Healthy control: 0.139 FP vs. Healthy control: 0.107	R
	Lower Lumbar	3.4 (17.2) (-4.1 to 10.9)	-0.2 (13.3) (-8.7 to 8.4)	-0.6 (5.6) (-8.7 to 7.6)	0.331	0.721	-	NR

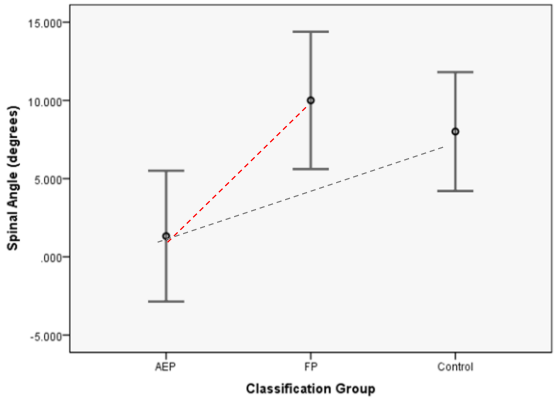
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni), (Exceptions: † = except Lower Lumbar n=13, Upper Lumbar n=15; ‡ = except Lower Lumbar n=10, Upper Lumbar n=16; ł = except Lower Lumbar n=11, Upper Lumbar n=19)

Total thoracic spine in full flexion



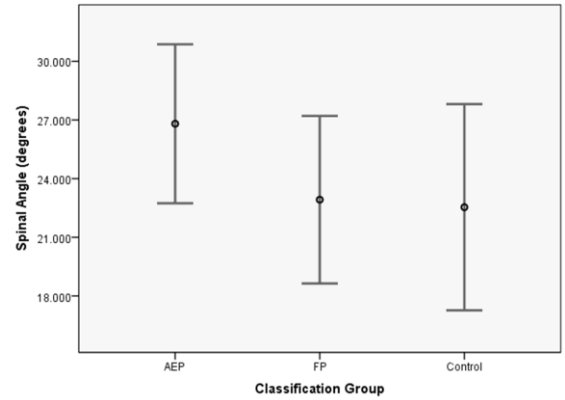
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine in full flexion



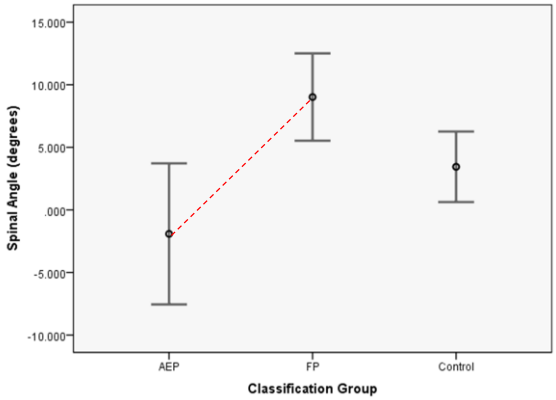
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine in full flexion



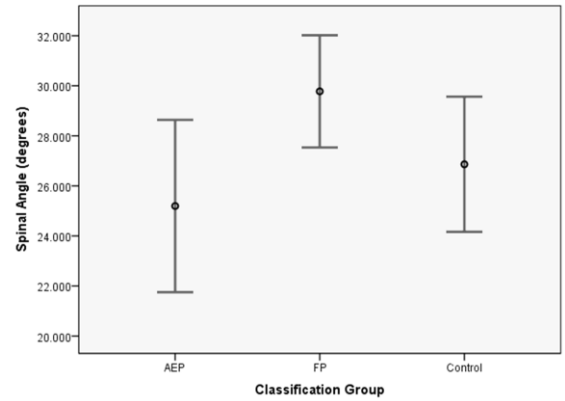
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine in full flexion



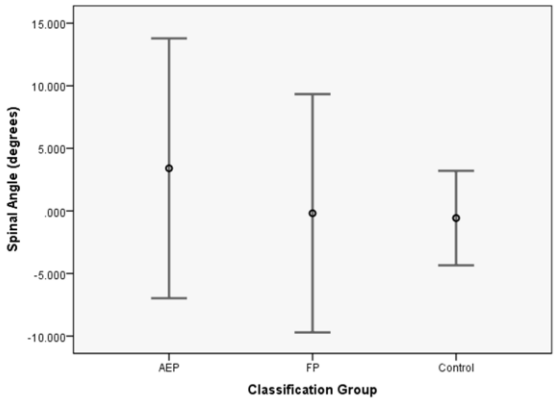
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine in full flexion



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine in full flexion



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 23: Flexion: 95% confidence intervals (error bars) for active extension pattern, flexion pattern and healthy control groups across six spinal segments

Total Spinal Angles – Flexion

The FP group achieved significantly greater maximum flexion angles in the total lumbar spine compared to AEP ($p=0.011$). Interestingly, the FP and healthy control groups appeared to adopt a similar maximum flexion angle in the total lumbar spine during flexion, and there was a general trend towards a difference between the AEP and healthy control group in this spinal region ($p=0.069$), however this did not reach significance. No significant between groups differences in maximum flexion spinal angle were observed in the total thoracic spine.

Regional Spinal Angles - Flexion

Significant differences were noted only between the FP and AEP groups in the upper lumbar spine ($p=0.001$), although a similar, non-significant, trend was observed in the lower thoracic spine ($p=0.064$). In both the upper lumbar and lower thoracic spinal regions the mean maximum spinal angle for the healthy control group lay between the FP and AEP groups and no significant between group differences between the healthy control and subclassified NSCLBP groups were identified. No significant differences in spinal angle in the upper thoracic or lower lumbar spine were observed between groups and no significant differences between the AEP and healthy control groups were identified in any total or regional spinal segment.

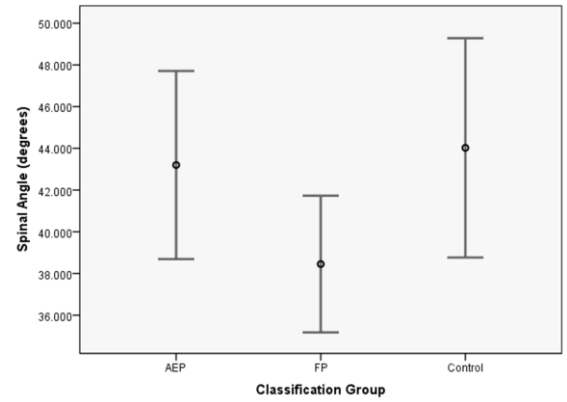
7.4.3.2 Extension

Table 25: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for extension between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23†	FP n=27‡	Healthy control n=28 ł	F	p		
Extension	Total Thoracic	43.2 (10.4) (38.6 to 47.8)	38.5 (8.3) (34.2 to 42.7)	44.0 (13.6) (39.9 to 48.2)	1.994	0.143	-	NR
	Total Lumbar	-50.4 (12.8) (-58.7 to -42.2)	-52.4 (23.6) (-59.8 to -45.0)	-53.1 (16.8) (-60.0 to -46.1)	0.120	0.887	-	NR
	Upper Thoracic	30.4 (7.4) (27.3 to 33.5)	25.1 (6.0) (22.3 to 28.0)	29.1 (8.6) (26.3 to 31.9)	3.529	0.034*	AEP vs. FP: 0.044* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.150	R
	Lower Thoracic	5.3 (18.2) (-0.9 to 11.6)	10.2 (10.7) (4.4 to 15.9)	7.3 (15.6) (1.7 to 13.0)	0.653	0.523	-	NR
	Upper Lumbar	-21.2 (14.9) (-27.0 to -15.5)	-12.7 (12.3) (-17.8 to -7.7)	-20.0 (12.7) (-25.0 to -15.1)	3.106	0.051	-	NR
	Lower Lumbar	-30.9 (23.1) (-41.8 to -19.9)	-44.1 (25.6) (-54.1 to -34.2)	-35.0 (24.4) (-44.4 to -25.6)	1.742	0.183	-	NR

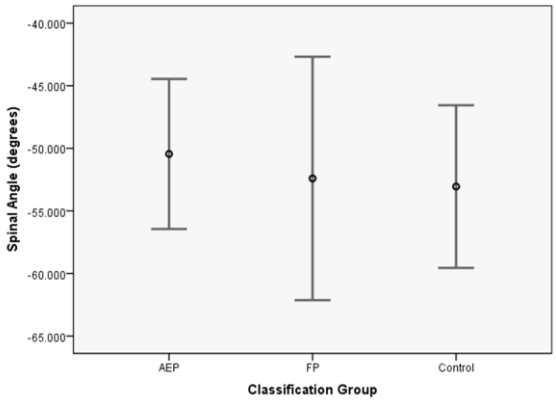
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni) (Exceptions: † = except Total Lumbar n=20, Lower Lumbar n=20, Upper Lumbar n=21; ‡ = except Total Lumbar n=25, Lower Lumbar n=24; ł = except Lower Lumbar n=28)

Total thoracic spine in full extension



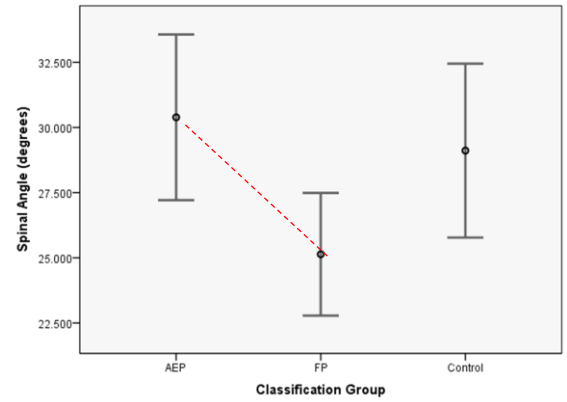
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine in full extension



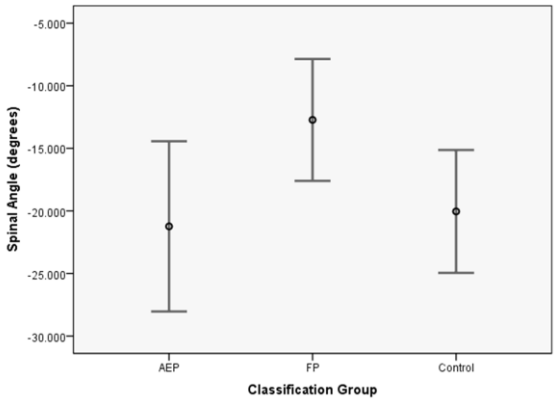
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine in full extension



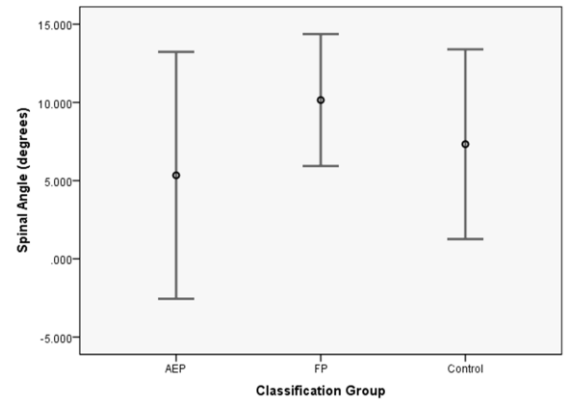
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine in full extension



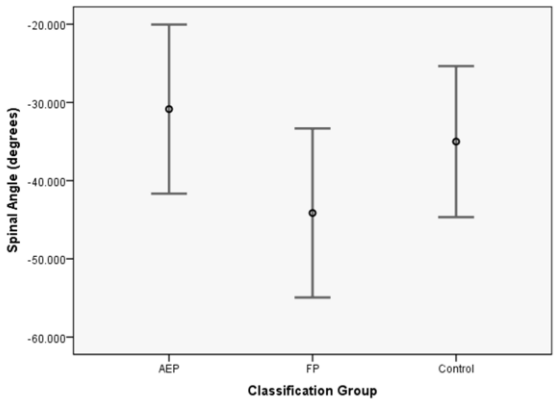
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine in full extension



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine in full extension



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 24: Extension: 95% confidence intervals (error bars) for active extension pattern, flexion pattern and healthy control groups across six spinal segments

Total Spinal Angles – Extension

No significant between groups differences in spinal angle were observed in the total thoracic and total lumbar spinal regions. In the total thoracic spine the AEP and healthy control groups appear to adopt a more flexed overall posture compared to the FP group although no significant differences were detected.

Regional Spinal Angles – Extension

Significant differences were noted in the upper thoracic spinal region during extension ($p=0.044$) with the FP group displaying greater extension in this region compared to the AEP group. No significant differences were observed in the lower thoracic, upper lumbar or lower lumbar spinal region, although visual inspection of the graphs revealed distinct patterns in each spinal region. In both the lower thoracic spine and upper lumbar spine the FP group appeared to operate in less extension compared to the AEP group. The one-way ANOVA of the upper lumbar spine region very narrowly missed significance ($p=0.051$) and this demonstrated a consistent pattern with the results of the static and functional tasks where the upper lumbar region appeared to be key area for discriminating between NSCLBP sub-groups and healthy control groups. In the lower lumbar spine the FP group appeared to operate in greater extension compared to the AEP group, however significance was not reached. For all regional spinal angles the healthy control group consistently adopted postures in a range between those of the FP and AEP groups. No significant between group differences in the AEP and healthy control, or FP and healthy control, groups were observed in any total or regional spinal segment.

7.4.3.3 Range of Movement: Significant Findings

For the ROM tasks significant differences were only observed in the total lumbar and upper lumbar spine during full flexion with the FP group operating in greater flexion compared to the AEP group. During full extension significant differences were only observed in the upper thoracic spinal region between the AEP and FP groups with the FP group interestingly adopting significantly more extended postures in this spinal region. This was the only spinal region throughout any posture or task to display these characteristics with statistical significance. No other significant differences were observed in any other spinal region in either ROM task.

For both ROM tasks (flexion / extension) the null hypothesis was not rejected for all spinal regions, i.e. there was no difference in sagittal spinal angles between MCI subgroups of NSCLBP subjects and healthy controls during full ROM. However the null hypothesis was rejected in the total and upper lumbar spine during flexion and the upper thoracic spine during extension to accept that differences in sagittal spinal angles between MCI subgroups of NSCLBP were present during full ROM.

7.4.4 Kinematics - Hierarchy of Functional Tasks

In order to evaluate which functional tasks operated in the greatest degree of flexion and extension, the overall mean (midpoint) ROM of the total lumbar spine angle for all subjects combined was evaluated (Figure 25) and for each group (AEP, FP and healthy control) (Figure 26) for each functional task was plotted.

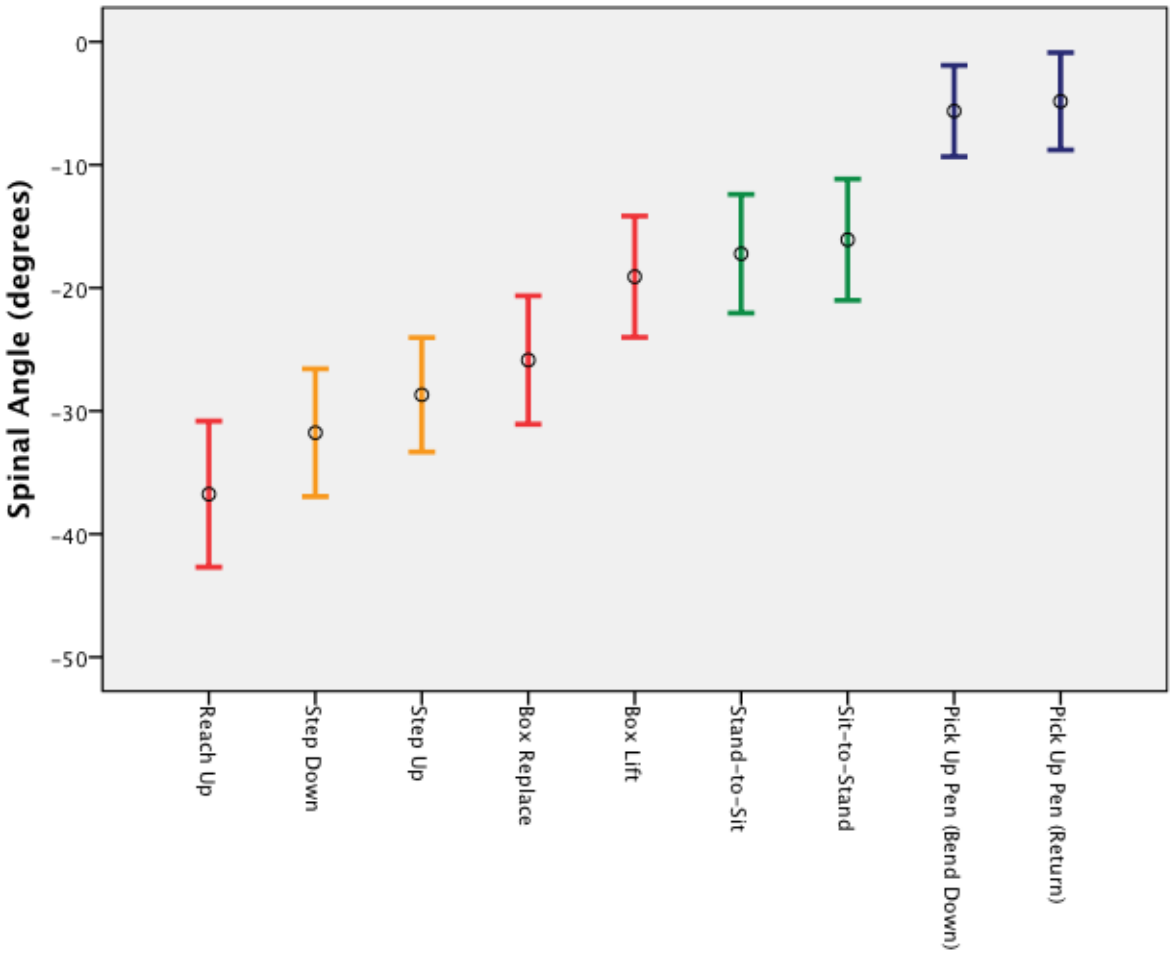
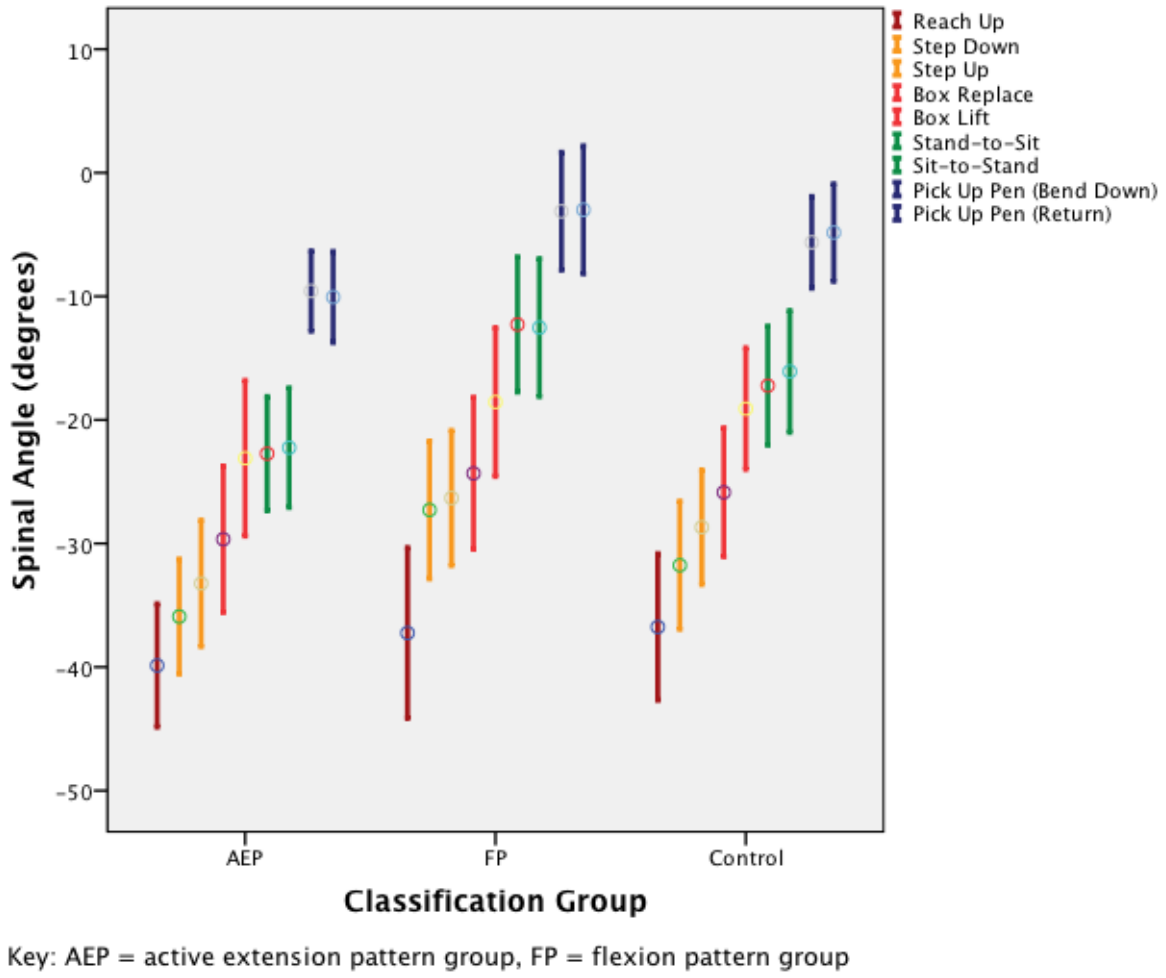


Figure 25: Error bar chart (95% confidence intervals) for the overall mean (midpoint) total lumbar spine angle for all subjects (active extension pattern, flexion pattern and healthy control group combined) during each functional task

As shown in Figure 25 the activity with the greatest degree of lumbar spinal extension was the reach up task. The task with the greatest degree of lumbar spine flexion was the pick up pen (return) task.



Key: AEP = active extension pattern group, FP = flexion pattern group

Figure 26: Clustered error bar chart (95% confidence intervals) for the mean (midpoint) total lumbar spine angle in the active extension pattern, flexion pattern and healthy control groups during each functional task

As shown in Figure 26, the overall hierarchy of ROM did not vary between groups. Therefore the results of each functional task in this section will be presented in this order, from the task with the greatest extension ROM bias (Reach up) to the task with the greatest flexion ROM bias (Pick Up Pen (Return)) to allow between group differences to be evaluated with regard to the direction-specificity of the task.

7.4.5 Kinematics – Tasks

Tables 26 to 34 detail the descriptive and inferential statistics, post-hoc tests and hypothesis testing for the reach up (Table 26) step down (Table 27), step up (Table 28), box replace (Table 29), box lift (Table 30), stand-to-sit (Table 31), sit-to-stand (Table 32), pick up pen (bend down) (Table 33) and pick up pen (return) (Table 34) tasks. Mean (midpoint) sagittal spinal angle, standard deviation and 95% confidence intervals for each spinal region are reported in degrees for all three groups. Results of the one-way ANOVA (F-statistic, p-value) and post-hoc Bonferroni test are stated and significant findings marked with an asterisk (*). Additionally, null hypothesis 3 is accepted or rejected.

Figures 27 to 35 present the mean (midpoint) ROM angle across the three groups (AEP, FP, healthy control) for each spinal segment during the reach up (Figure 27) step down (Figure 28), step up (Figure 29), box replace (Figure 30), box lift (Figure 31), stand-to-sit (Figure 32), sit-to-stand (Figure 33), pick up pen (bend down) (Figure 34) and pick up pen (return) (Figure 35) tasks. The upper extreme indicates the mean maximum flexion angle for each group and conversely the lower extreme indicates the mean maximum extension angle for each group. Positive values (above zero) indicate flexion and negative values (below zero) indicate extension. A red dashed line indicates where significant differences ($p<0.05$) between groups have been observed. A grey dashed line indicates a general trend ($p<0.1$).

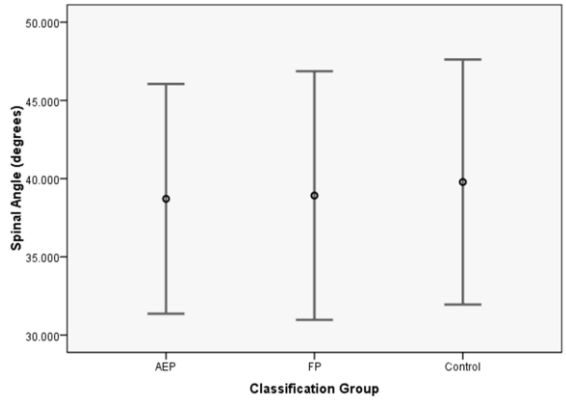
7.4.5.1 Reach Up

Table 26: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the reach up task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23	FP n=27	Healthy control n=28	F	p		
Reach Up	Total Thoracic	38.7 (10.4) (34.9 to 42.5)	38.9 (8.1) (35.4 to 42.4)	39.8 (9.1) (36.3 to 43.2)	0.101	0.904	-	NR
	Total Lumbar	-40.3 (10.4) (-46.4 to -34.3)	-37.2 (16.8) (-42.8 to -31.6)	-36.8 (15.3) (-42.3 to -31.3)	0.431	0.651	-	NR
	Upper Thoracic	27.2 (8.2) (23.9 to 30.5)	25.3 (7.8) (22.3 to 28.3)	27.1 (7.6) (24.2 to 30.1)	0.485	0.618	-	NR
	Lower Thoracic	4.4 (13.1) (-0.2 to 9.1)	11.1 (9.2) (6.8 to 15.4)	6.4 (11.4) (2.2 to 10.6)	2.344	0.103	-	NR
	Upper Lumbar	-19.2 (12.0) (-23.3 to -15.0)	-11.0 (10.0) (-14.8 to -7.2)	-17.4 (8.0) (-21.2 to -13.7)	4.824	0.011*	AEP vs. FP: 0.015* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.058	R
	Lower Lumbar	-23.3 (19.8) (-30.5 to -16.0)	-29.9 (18.5) (-36.6 to -23.2)	-22.6 (13.9) (-29.2 to -16.0)	1.426	0.247	-	NR

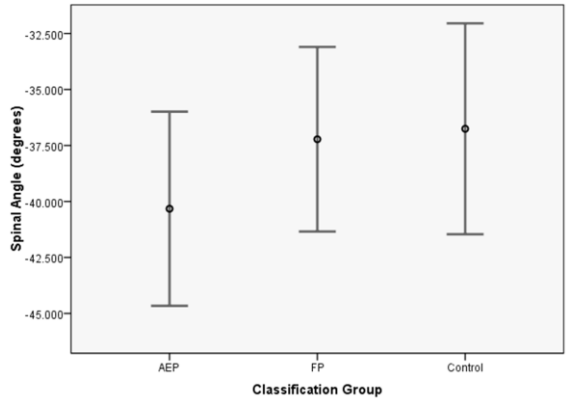
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine during reach up



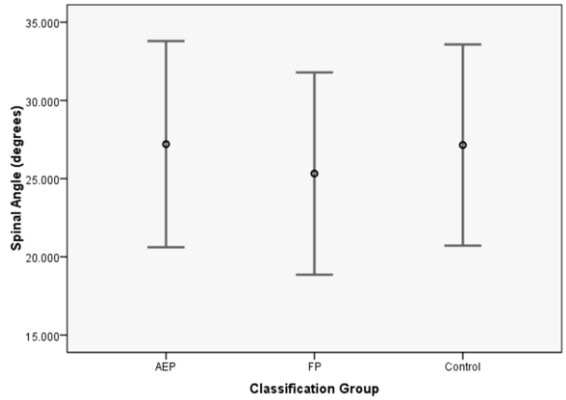
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during reach up



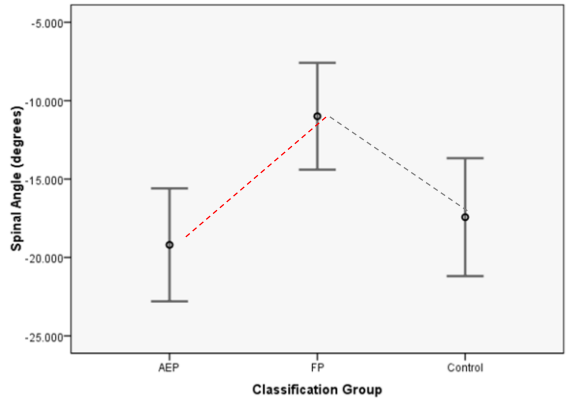
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during reach up



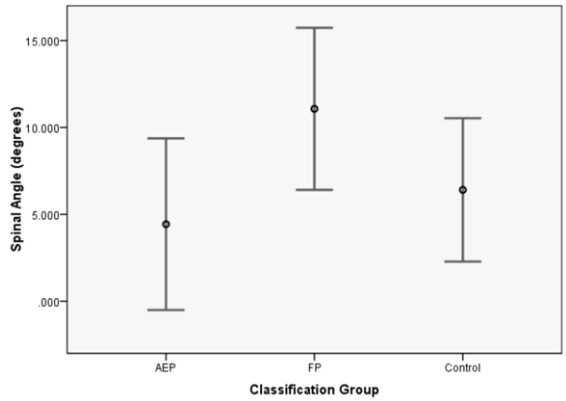
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during reach up



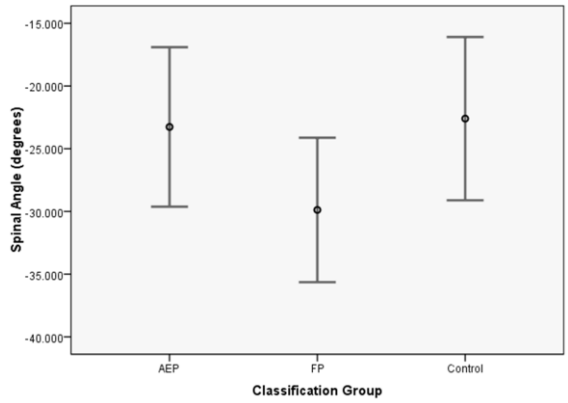
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during reach up



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during reach up



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 27: Reach Up: Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)

Total Spinal Angles – Reach Up

No significant between groups differences in spinal angle were observed in the total thoracic and total lumbar spinal regions. Both the FP and healthy control groups appeared to operate in greater flexion in the total lumbar spine, compared to the AEP group, during the reaching task however a one-way ANOVA found this difference to not be significant (p=0.651).

Regional Spinal Angles – Reach Up

Significant differences were noted in the upper lumbar region (p=0.015) between the FP and AEP groups with the FP group operating in greater flexion throughout the reaching task compared to the AEP group. In this spinal region the healthy control group appeared to operate in a similar range to that of the AEP group, with a consistent pattern observed between the FP and healthy control group with the FP group operating in greater flexion in this spinal region, however this did not reach significance (p=0.058). No significant differences were observed in the lower thoracic, upper lumbar or lower lumbar spinal region, although visual inspection of the graphs revealed distinct patterns in the lower thoracic and lower lumbar spinal regions. In the lower thoracic spine the FP group appeared to operate in more flexion compared to the AEP group. A reversal of this pattern was apparent in the lower lumbar spine with the FP group appearing to operate in greater extension compared to the AEP group. In both the upper lumbar and lower thoracic spine the healthy control group consistently adopted postures in a range between those of the FP and AEP groups. In the upper thoracic and lower lumbar spine the healthy control group mean ROM appeared to be consistently similar to that of the AEP group. No significant between group differences in AEP and healthy control subjects were observed in any total or regional spinal segment.

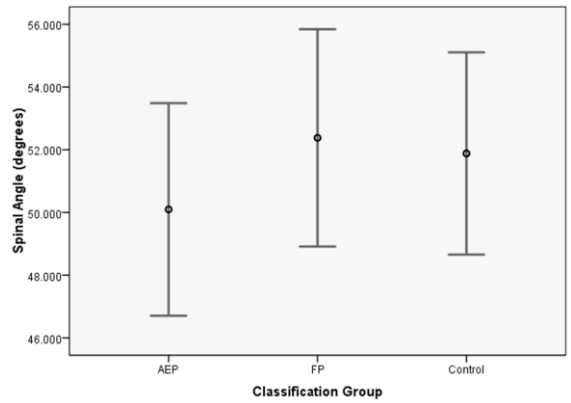
7.4.5.2 Step Down

Table 27: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the step down task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23	FP n=27	Healthy control n=28	F	p		
Step Down	Total Thoracic	50.1 (10.4) (46.4 to 53.8)	52.4 (7.9) (48.9 to 55.8)	51.9 (8.8) (48.5 to 55.3)	0.433	0.650	-	NR
	Total Lumbar	-36.3 (9.4) (-41.4 to -31.1)	-27.3 (13.6) (-32.0 to -22.5)	-31.8 (13.4) (-36.4 to -27.1)	3.248	0.044*	AEP vs. FP:0.039* AEP vs. Healthy control: 0.609 FP vs. Healthy control: 0.554	R
	Upper Thoracic	34.5 (8.2) (31.3 to 37.7)	33.8 (7.9) (30.9 to 36.8)	35.2 (6.9) (32.3 to 38.0)	0.206	0.815	-	NR
	Lower Thoracic	9.5 (13.2) (5.0 to 14.0)	18.4 (9.1) (14.2 to 22.6)	12.6 (10.3) (8.5 to 16.7)	4.353	0.016*	AEP vs. FP: 0.016* AEP v. Healthy control: 0.959 FP vs. Healthy control: 0.155	R
	Upper Lumbar	-18.0 (11.8) (-22.1 to -13.9)	-8.1 (9.5) (-11.9 to -4.3)	-15.1 (8.4) (-18.9 to -11.4)	6.902	0.002*	AEP vs. FP: 0.002* AEP vs. Healthy control: 0.908 FP vs. Healthy control: 0.029*	R
	Lower Lumbar	-21.1 (20.8) (-27.7 to -14.5)	-23.7 (16.1) (-29.8 to -17.6)	-20.2 (9.9) (-26.2 to -14.3)	0.341	0.712	-	NR

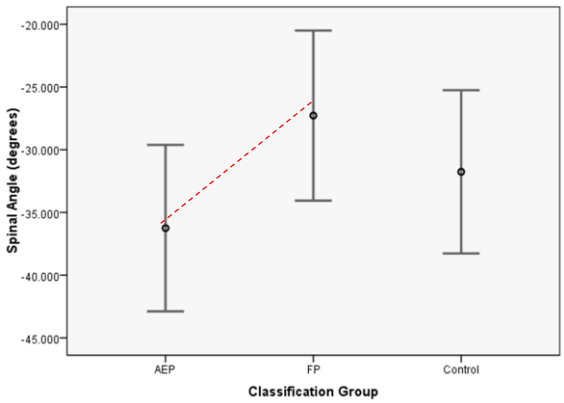
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine during step down



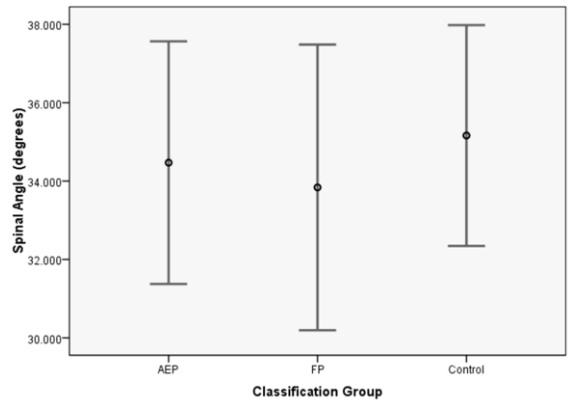
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during step down



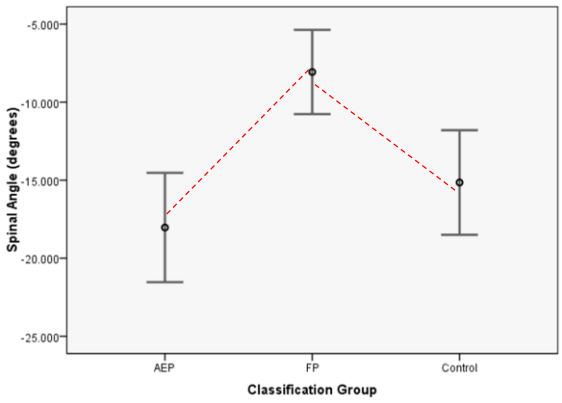
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during step down



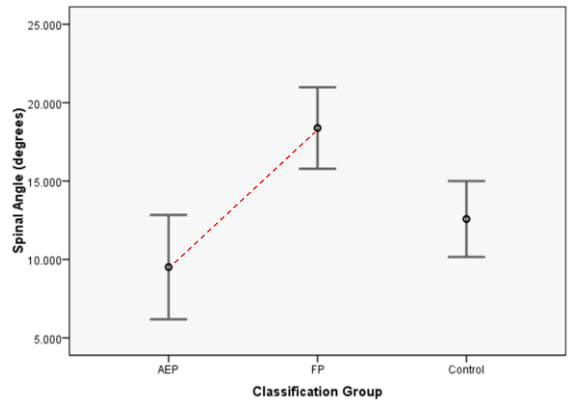
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during step down



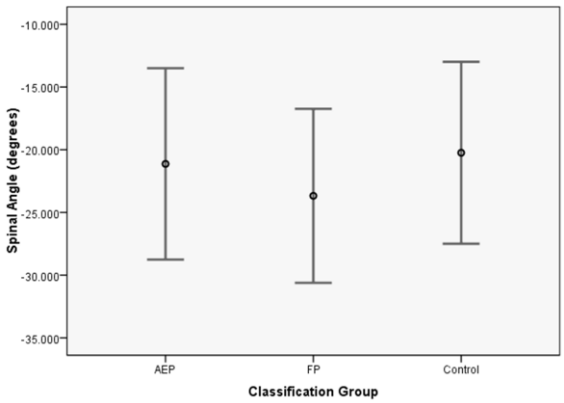
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during step down



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during step down



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 28: Step Down: Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)

Total Spinal Angles – Step Down

Significant differences were noted in the total lumbar spine between the FP and AEP groups ($p=0.039$) with the FP group operating in greater flexion compared to the AEP group. In the total lumbar spine the healthy control group mean (midpoint) ROM was observed to lie between that of the NSCLBP sub-groups. No significant between group differences in spinal angle were observed in the total thoracic spinal region.

Regional Spinal Angles – Step Down

Significant differences were noted between the FP and AEP groups in both the upper lumbar spine ($p=0.002$) and the lower thoracic spine ($p=0.016$) with the FP group operating in much greater flexion compared with the AEP group. In both the upper lumbar and lower thoracic spinal regions, a similar pattern of increased flexion in the FP group when compared with the healthy control group was notable however, significance was only observed in the upper lumbar spine ($p=0.029$). No significant differences were noted in either the upper thoracic or lower lumbar regions. No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

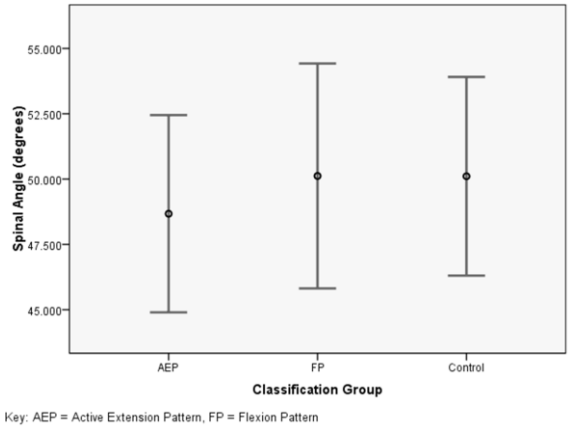
7.4.5.3 Step Up

Table 28: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the step up task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23	FP n=27	Healthy control n=28	F	p		
Step Up	Total Thoracic	48.7 (10.2) (44.9 to 52.4)	50.1 (7.9) (46.7 to 53.6)	50.1 (9.0) (46.7 to 53.5)	0.208	0.813	-	NR
	Total Lumbar	-33.4 (10.3) (-38.4 to -28.4)	-26.4 (13.3) (-31.0 to -21.8)	-28.7 (12.0) (-33.2 to -24.2)	2.177	0.120	-	NR
	Upper Thoracic	33.1 (7.5) (30.0 to 36.1)	32.1 (7.4) (29.3 to 34.8)	34.1 (6.9) (31.3 to 36.8)	0.521	0.596	-	NR
	Lower Thoracic	10.0 (12.5) (5.5 to 14.4)	18.0 (9.2) (13.9 to 22.0)	11.8 (10.3) (7.8 to 15.8)	3.967	0.023*	AEP vs. FP: 0.030* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.107	R
	Upper Lumbar	-17.0 (11.2) (-20.9 to -13.2)	-7.3 (8.9) (-10.8 to -3.8)	-14.1 (7.8) (-17.5 to -10.6)	7.432	0.001*	AEP vs. FP: 0.001* AEP vs. Healthy control: 0.771 FP vs. Healthy control: 0.025*	R
	Lower Lumbar	-19.0 (19.6) (-25.3 to -12.6)	-22.8 (15.7) (-28.7 to -11.6)	-17.4 (9.9) (-23.1 to -11.6)	0.922	0.402	-	NR

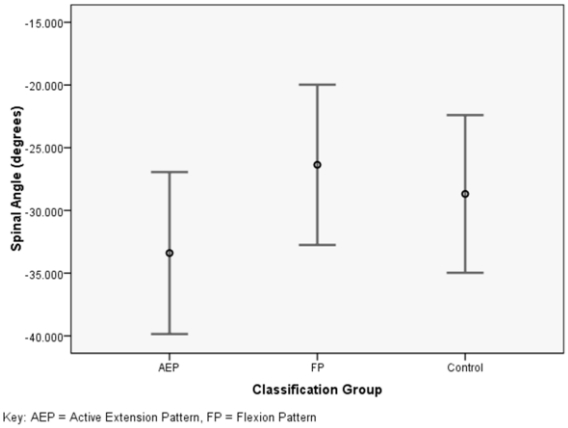
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine during step up



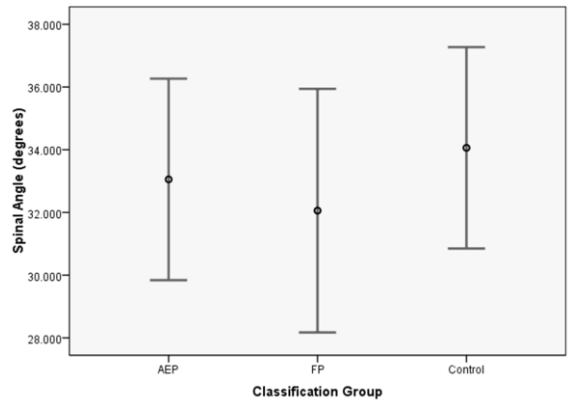
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during step up



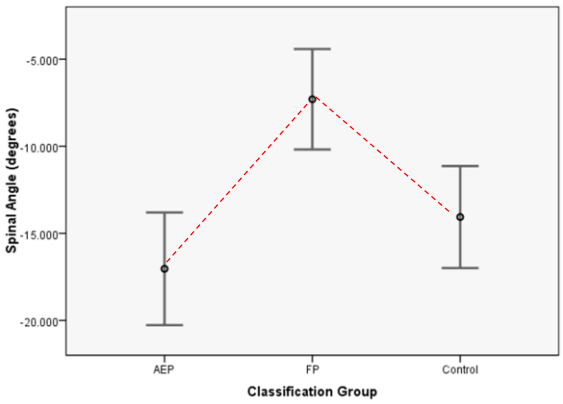
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during step up



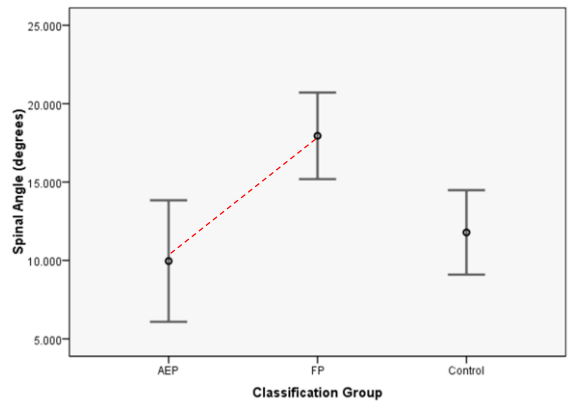
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during step up



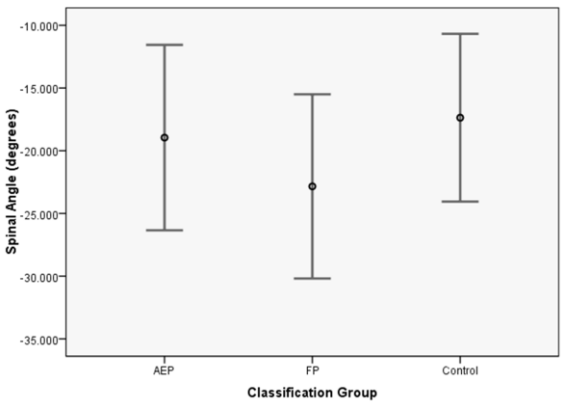
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during step up



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during step up



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 29: Step Up: Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)

Total Spinal Angles – Step Up

No significant between groups differences in spinal angle were observed in the total thoracic and total lumbar spinal regions.

Regional Spinal Angles – Step Up

Significant differences were noted between the FP and AEP groups in the upper lumbar spine ($p=0.001$) with the FP group operating in much greater flexion compared with the AEP group. Similarly this pattern was observed in the lower thoracic spine ($p=0.030$). In both the upper lumbar and lower thoracic spinal regions, a similar pattern of increased flexion in the FP group when compared with the healthy control group was notable, however significance was only attained in the upper lumbar spine ($p=0.025$). No significant differences were noted in either the upper thoracic or lower lumbar regions. No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

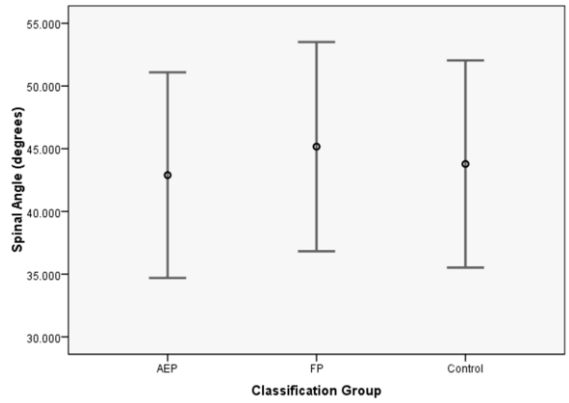
7.4.5.4 Box Replace

Table 29: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the box replace task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23	FP n=26	Healthy control n=28	F	p		
Box Replace	Total Thoracic	42.9 (10.3) (39.2 to 46.6)	45.2 (8.2) (41.7 to 48.6)	43.8 (8.1) (40.4 to 47.1)	0.412	0.664	-	NR
	Total Lumbar	-30.6 (12.3) (-36.3 to -24.9)	-24.3 (15.2) (-29.7 to -18.9)	-25.9 (13.5) (-31.0 to -20.7)	1.350	0.266	-	NR
	Upper Thoracic	26.8 (8.5) (23.5 to 30.0)	25.4 (7.2) (22.3 to 28.4)	26.6 (7.7) (23.7 to 29.6)	0.238	0.789	-	NR
	Lower Thoracic	13.0 (10.0) (8.9 to 17.1)	21.7 (8.2) (17.9 to 25.5)	15.5 (11.0) (11.8 to 19.2)	5.231	0.007*	AEP vs. FP: 0.008* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.068	R
	Upper Lumbar	-13.8 (10.9) (-17.5 to -10.1)	-3.8 (8.6) (-7.3 to -0.3)	-10.1 (7.4) (-13.5 to -6.7)	7.844	0.001*	AEP vs. FP: 0.001* AEP vs. Healthy control: 0.439 FP vs. Healthy control: 0.036*	R
	Lower Lumbar	-20.5 (17.3) (-26.1 to -14.8)	-24.7 (13.5) (-30.1 to -19.3)	-18.9 (10.1) (-24.1 to -13.8)	1.258	0.290	-	NR

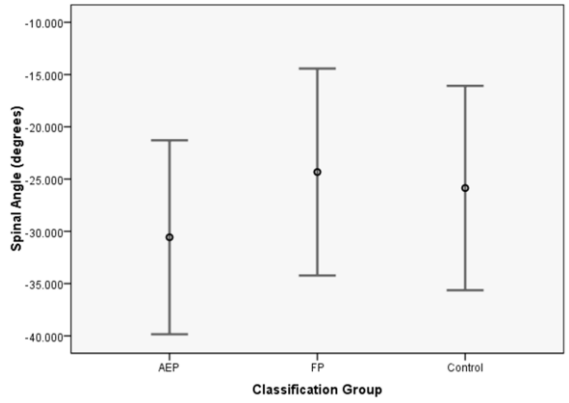
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine during box replace



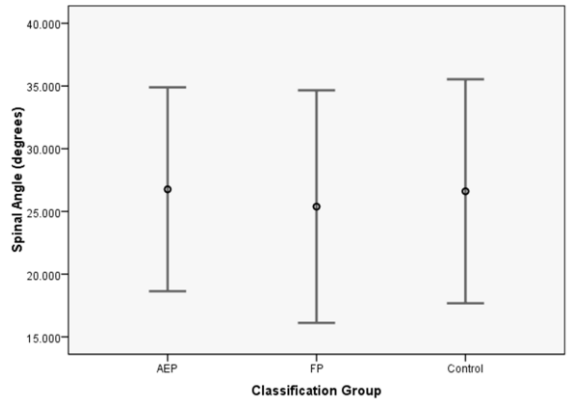
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during box replace



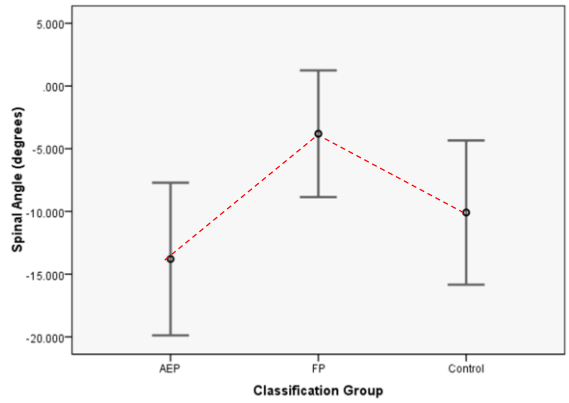
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during box replace



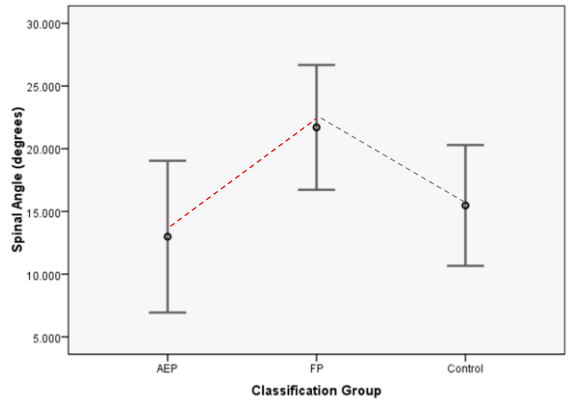
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during box replace



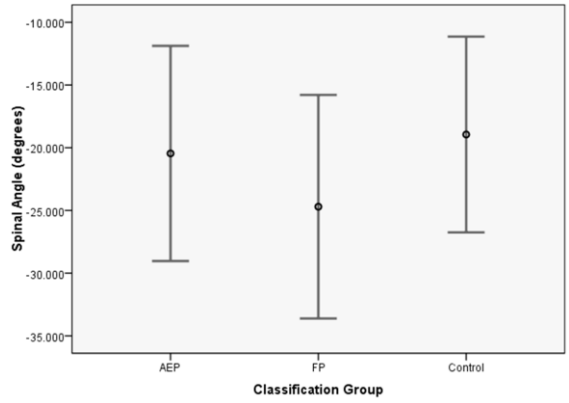
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during box replace



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during box replace



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 30: Box Replace: Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)

Total Spinal Angles – Box Replace

No significant between groups differences in spinal angle were observed in the total thoracic and total lumbar spinal regions.

Regional Spinal Angles – Box Replace

Significant differences were noted between the FP and AEP groups in both the upper lumbar ($p=0.001$) and lower thoracic ($p=0.008$) spine with the FP group operating in much greater flexion compared with the AEP group in both spinal regions. In both the upper lumbar spinal regions, a similar pattern of significantly increased flexion in the FP group when compared with the healthy control group is notable ($p=0.036$). This general trend is reflected in the lower thoracic spinal region, however this does not reach significance ($p=0.068$). No significant differences were noted in either the upper thoracic or lower lumbar regions. No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

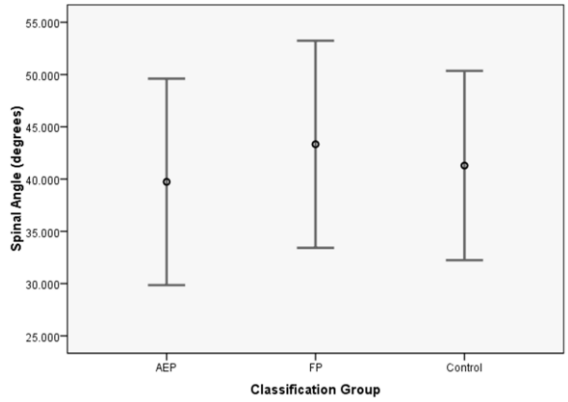
7.4.5.5 Box Lift

Table 30: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the box lift task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=23	FP n=26	Healthy control n=28	F	p		
Box Lift	Total Thoracic	39.7 (11.9) (35.7 to 43.8)	43.3 (8.9) (39.5 to 47.1)	41.3 (8.4) (37.6 to 45.0)	0.846	0.433	-	NR
	Total Lumbar	-23.3 (13.0) (-28.9 to -17.7)	-18.6 (12.7) (-23.9 to -13.3)	-19.1 (12.7) (-24.2 to -14.0)	0.883	0.418	-	NR
	Upper Thoracic	23.3 (9.9) (19.7 to 26.8)	23.9 (7.1) (20.5 to 27.2)	24.0 (8.5) (20.8 to 27.2)	0.049	0.952	-	NR
	Lower Thoracic	14.1 (9.8) (10.2 to 18.0)	22.4 (7.9) (18.8 to 26.1)	16.7 (10.2) (13.2 to 20.2)	5.144	0.008*	AEP vs. FP: 0.008* AEP vs. Healthy control: 0.994 FP vs. Healthy control: 0.083	R
	Upper Lumbar	-11.6 (9.4) (-15.2 to -8.0)	-2.4 (9.4) (-5.8 to 1.0)	-7.5 (7.5) (-10.8 to -4.2)	6.849	0.002*	AEP vs. FP: 0.001* AEP vs. Healthy control: 0.307 FP vs. Healthy control: 0.102	R
	Lower Lumbar	-14.8 (16.7) (-20.4 to -9.2)	-20.4 (13.7) (-25.6 to -15.1)	-15.0 (9.7) (-20.1 to -10.0)	1.426	0.247	-	NR

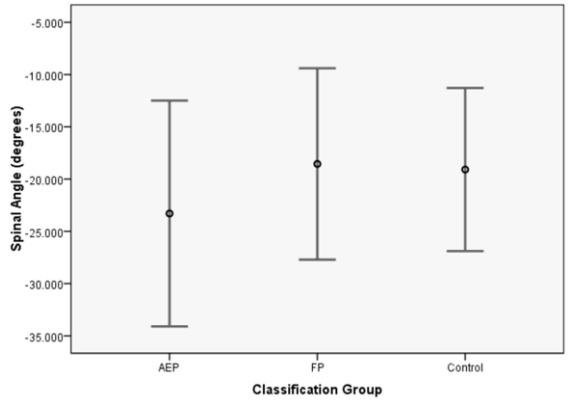
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine during box lift



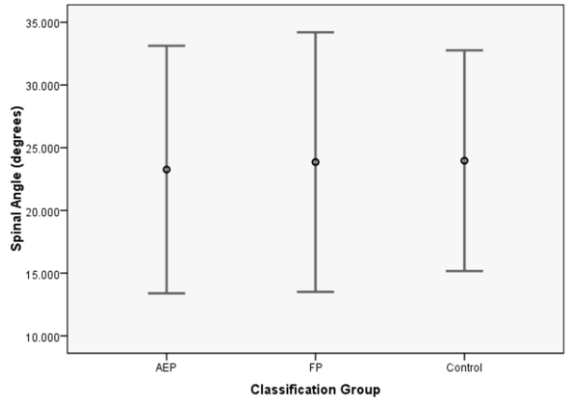
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during box lift



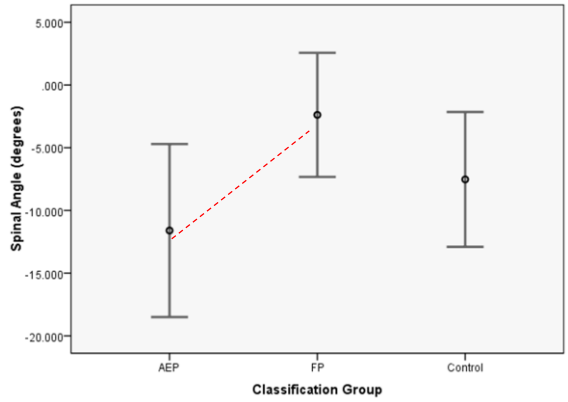
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during box lift



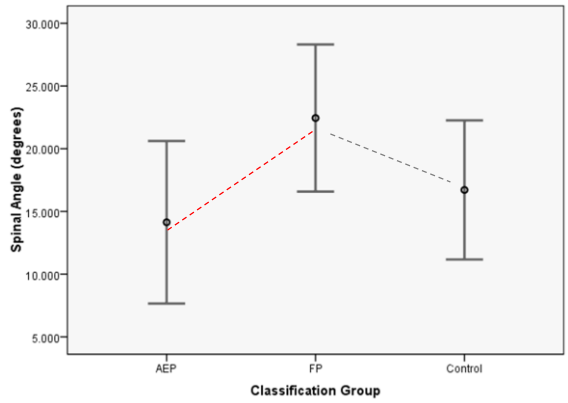
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during box lift



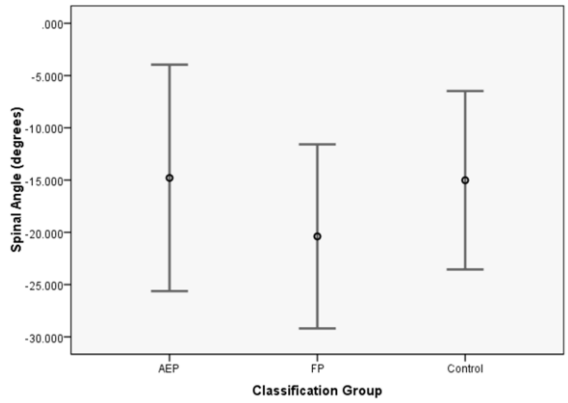
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during box lift



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during box lift



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 31: Box Lift: Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)

Total Spinal Angles – Box Lift

No significant between groups differences in spinal angle were observed in the total thoracic and total lumbar spinal regions.

Regional Spinal Angles – Box Lift

Significant differences were noted between the FP and AEP groups in both the upper lumbar ($p=0.001$) and lower thoracic ($p=0.008$) spine with the FP group operating in greater flexion compared with the AEP group in both spinal regions. In the lower thoracic spinal region, a general trend towards increased flexion in the FP group when compared with the healthy control group was notable however this was not significant ($p=0.083$). No significant differences were noted in either the upper thoracic or lower lumbar regions. No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

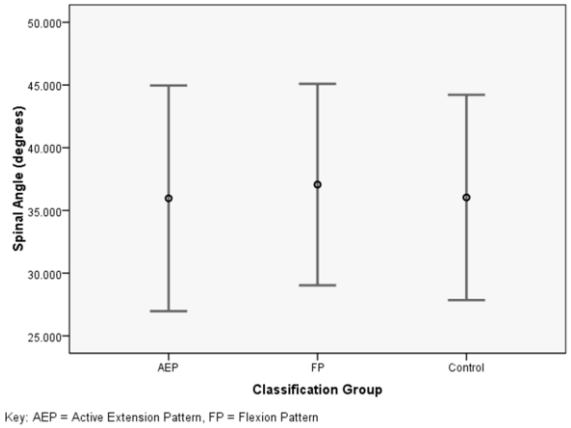
7.4.5.6 Stand-to-Sit

Table 31: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the stand-to-sit task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=22	FP n=27	Healthy control n=28	F	p		
Stand-to-Sit	Total Thoracic	36.0 (10.3) (31.9 to 40.0)	37.1 (8.4) (33.4 to 40.7)	36.0 (10.0) (32.5 to 39.6)	0.109	0.897	-	NR
	Total Lumbar	-23.1 (9.8) (-28.3 to -18.0)	-12.6 (13.4) (-17.3 to -8.0)	-17.2 (12.4) (-21.8 to -12.7)	4.574	0.013*	AEP vs. FP: 0.010* AEP vs. Healthy control: 0.273 FP vs. Healthy control: 0.488	R
	Upper Thoracic	22.1 (8.8) (18.8 to 25.4)	20.5 (6.7) (17.6 to 23.5)	22.5 (7.8) (19.6 to 25.4)	0.480	0.621	-	NR
	Lower Thoracic	8.8 (11.2) (4.5 to 13.1)	18.1 (8.5) (14.2 to 22.0)	10.7 (10.9) (6.8 to 14.5)	5.997	0.004*	AEP vs. FP: 0.006* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.025*	R
	Upper Lumbar	-11.9 (9.7) (-15.4 to -8.3)	-0.8 (8.5) (-4.0 to 2.5)	-6.3 (7.3) (-9.4 to -3.1)	10.530	<0.001*	AEP vs. FP: <0.001* AEP vs. Healthy control: 0.067 FP vs. Healthy control: 0.055	R
	Lower Lumbar	-11.6 (15.0) (-16.6 to -6.5)	-12.0 (11.6) (-16.6 to -7.4)	-9.7 (9.4) (-14.2 to -5.2)	0.292	0.748	-	NR

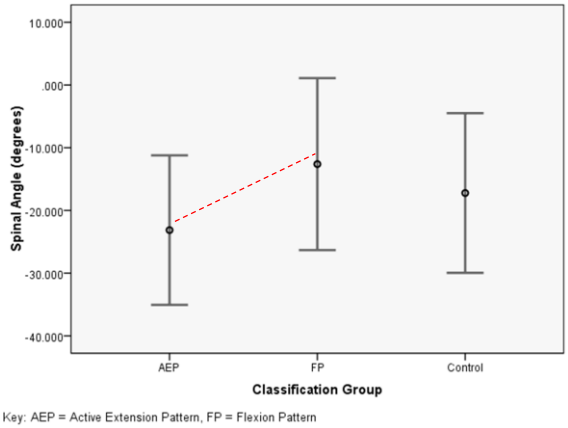
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine during stand-to-sit



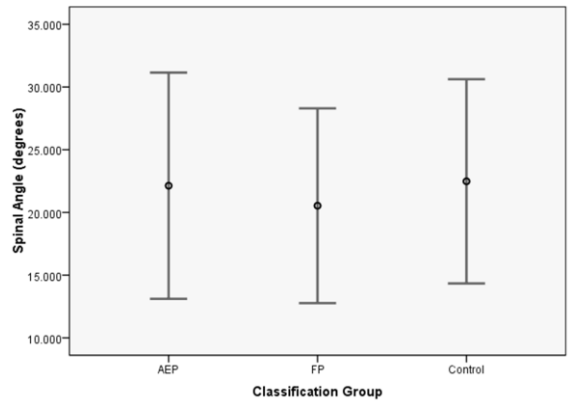
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during stand-to-sit



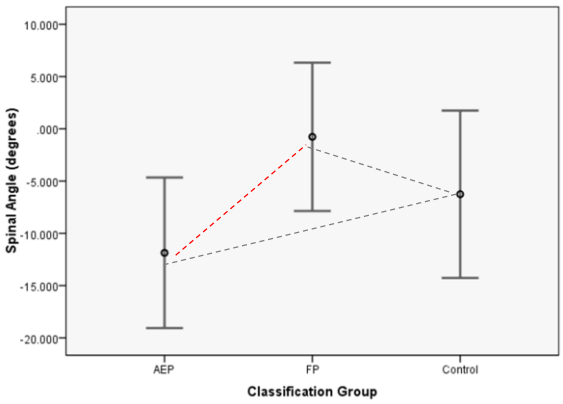
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during stand-to-sit



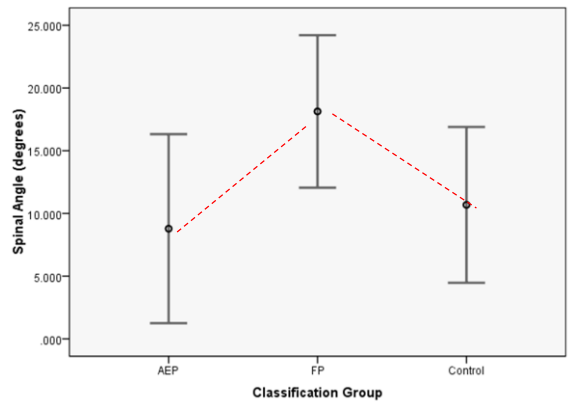
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during stand-to-sit



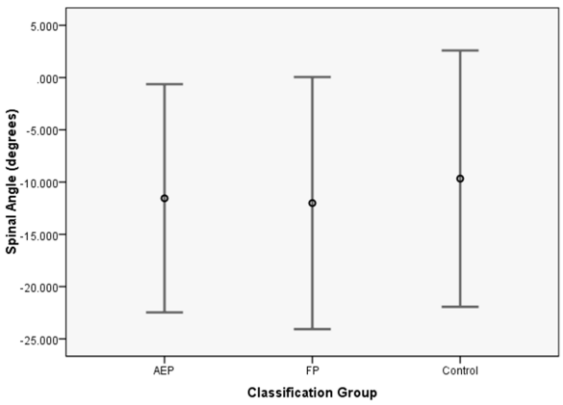
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during stand-to-sit



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during stand-to-sit



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 32: Stand-to-Sit: Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)

Total Spinal Angles – Stand-to-Sit

The FP group were observed to operate in significantly greater flexion in the total lumbar spine compared to the AEP group during the stand-to-sit task. No significant differences between the NSCLBP groups and the healthy control group were observed. No significant between groups differences in spinal angle were observed in the total thoracic spine.

Regional Spinal Angles – Stand-to-Sit

Significant differences were noted between the FP and AEP groups in both the upper lumbar ($p<0.001$) and lower thoracic ($p=0.006$) spine with the FP group operating in greater flexion compared with the AEP group in both spinal regions. In both the lower thoracic spinal region, a similar pattern of significantly increased flexion in the FP group when compared with the healthy control group was notable ($p=0.025$). A similar general trend was observed in the upper lumbar spine region between the FP and healthy control group however this narrowly missed significance ($p=0.055$). Interestingly in the upper lumbar region there was a general trend between the AEP and healthy control groups with the AEP group appearing to adopt greater extension in this spinal region, although this was not significant ($p=0.067$). No significant differences were noted in either the upper thoracic or lower lumbar regions. No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

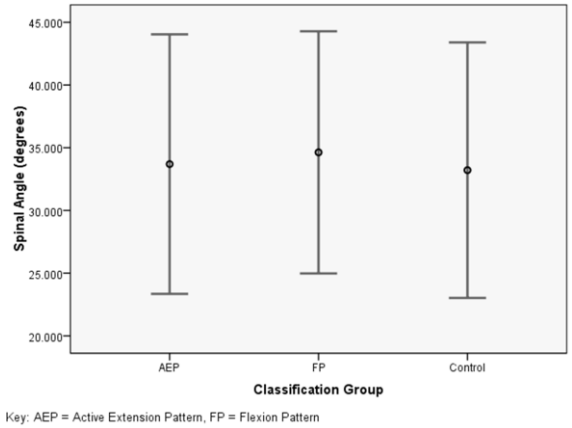
7.4.5.7 Sit-to-Stand

Table 32: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the sit-to-stand task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=22	FP n=27	Healthy control n=28	F	p		
Sit-to-Stand	Total Thoracic	33.7 (10.5) (29.6 to 37.8)	34.6 (8.9) (31.0 to 38.3)	33.2 (9.4) (29.6 to 36.8)	0.156	0.856	-	NR
	Total Lumbar	-22.2 (9.9) (-27.5 to -16.9)	-13.1 (13.9) (-17.9 to -8.3)	-16.1 (12.7) (-20.8 to -11.4)	3.334	0.041*	AEP vs. FP: 0.038* AEP vs. Healthy control: 0.262 FP vs. Healthy control: 1.000	R
	Upper Thoracic	20.4 (8.7) (17.3 to 23.6)	18.8 (6.2) (16.0 to 21.7)	20.6 (7.4) (17.8 to 23.4)	0.454	0.637	-	NR
	Lower Thoracic	7.8 (11.0) (3.5 to 12.1)	17.6 (8.1) (13.7 to 21.5)	9.9 (11.2) (6.1 to 13.7)	6.638	0.002*	AEP vs. FP: 0.004* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.018*	R
	Upper Lumbar	-10.6 (8.7) (-14.1 to -7.1)	-0.6 (8.3) (-3.7 to 2.5)	-5.4 (7.6) (-8.5 to -2.3)	9.050	<0.001*	AEP vs. FP: <0.001* AEP vs. Healthy control: 0.090 FP vs. Healthy control: 0.096	R
	Lower Lumbar	-11.0 (15.8) (-16.2 to -5.8)	-11.3 (12.0) (-16.0 to -6.6)	-9.0 (8.9) (-13.6 to -4.3)	0.283	0.755	-	NR

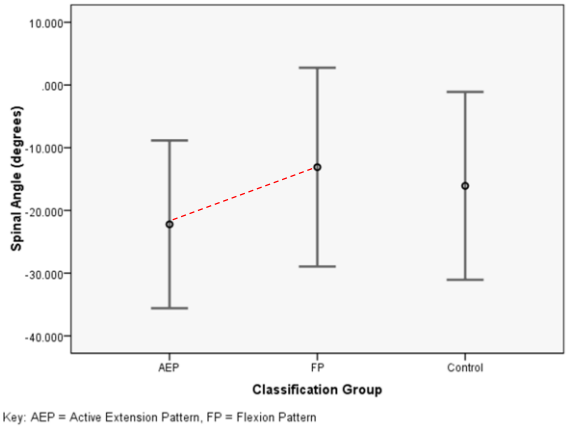
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni)

Total thoracic spine during sit-to-stand



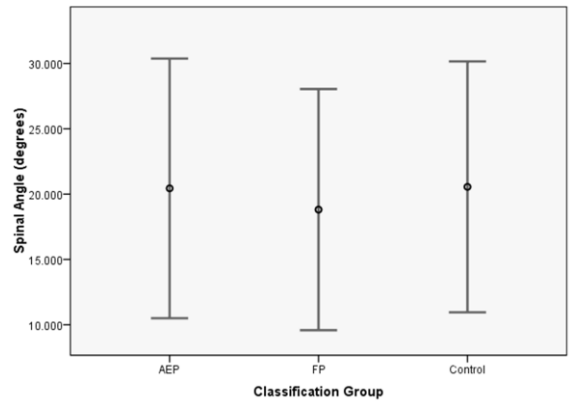
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during sit-to-stand



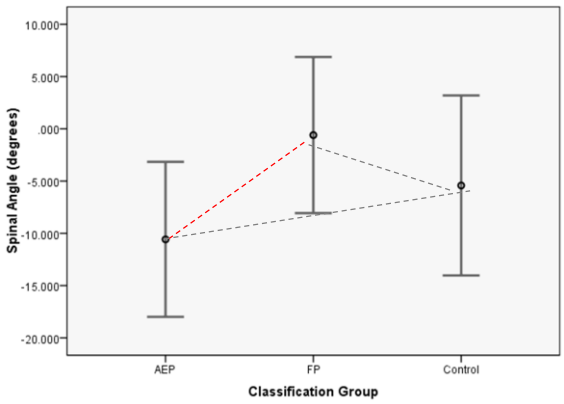
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during sit-to-stand



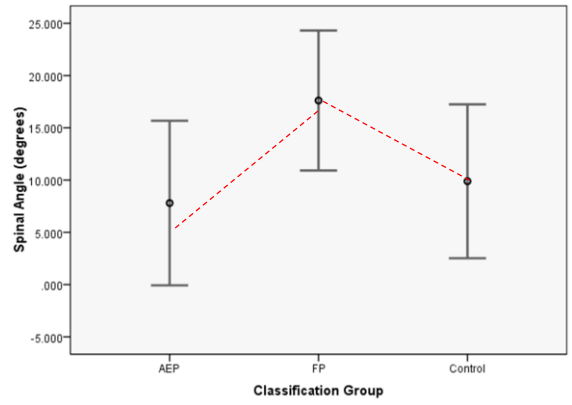
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during sit-to-stand



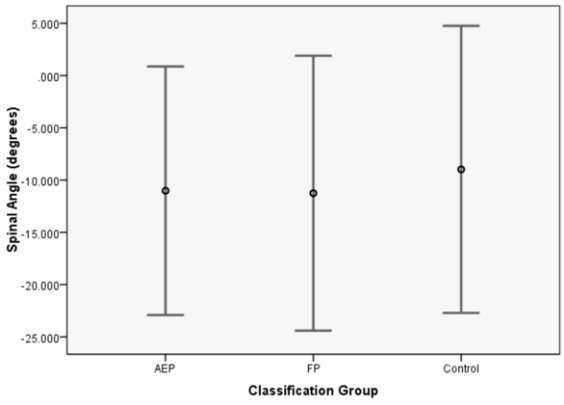
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during sit-to-stand



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during sit-to-stand



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 33: Sit-to-Stand: Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)
Total Spinal Angles – Sit-to-Stand

Significant differences were observed in the total lumbar spine between the FP and AEP groups ($p=0.038$) with the FP group operating in greater flexion compared to the AEP group. No significant between group differences in spinal angle were observed in the total thoracic spinal region.

Regional Spinal Angles – Sit-to-Stand

Significant differences were noted between the FP and AEP groups in both the upper lumbar ($p<0.001$) and lower thoracic ($p=0.004$) spine with the FP group operating in greater flexion compared with the AEP group in both spinal regions. In the lower thoracic spinal regions a similar pattern of increased flexion in the FP group compared with the healthy control group was notable ($p=0.018$). Similarly this trend was observed in the upper lumbar spine region however this did not reach significance ($p=0.096$). Additionally, as observed in the stand-to-sit task, a general pattern of increased extension in the AEP group compared to the healthy control group was observed in the upper lumbar region, although significance was not reached ($p=0.090$). No significant differences were noted in either the upper thoracic or lower lumbar regions. No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

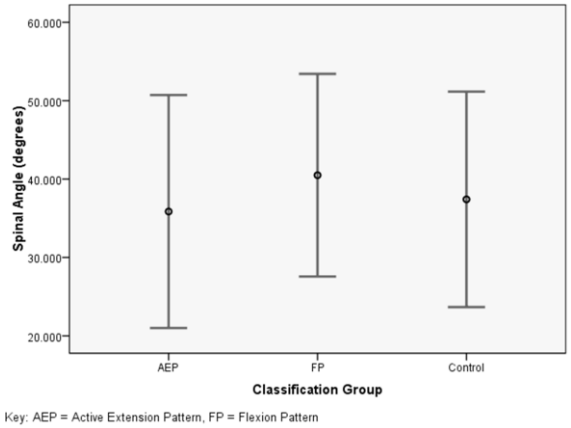
7.4.5.8 Pick Up Pen (Bend Down)

Table 33: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the pick up pen (bend down) task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=21	FP n=27‡	Healthy control n=28	F	p		
Pick up Pen (Bend Down)	Total Thoracic	35.9 (11.9) (31.6 to 40.1)	40.5 (8.7) (36.8 to 44.2)	37.4 (8.9) (33.7 to 41.1)	1.436	0.245	-	NR
	Total Lumbar	-9.5 (6.8) (-13.7 to -5.2)	-3.2 (11.6) (-6.9 to 0.5)	-5.6 (9.6) (-9.3 to -2.0)	2.463	0.092	-	NR
	Upper Thoracic	17.2 (10.5) (13.2 to 21.2)	19.2 (9.0) (15.7 to 22.7)	18.8 (8.2) (15.4 to 22.3)	0.296	0.745	-	NR
	Lower Thoracic	20.4 (9.9) (17.0 to 23.9)	26.4 (6.6) (23.4 to 29.5)	20.4 (7.4) (17.4 to 23.4)	5.027	0.009*	AEP vs. FP: 0.033* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.018*	R
	Upper Lumbar	-1.6 (7.0) (-4.3 to 1.1)	4.3 (6.3) (1.9 to 6.8)	0.1 (5.3) (-2.2 to 2.4)	5.830	0.005*	AEP vs. FP: 0.005* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.044*	R
	Lower Lumbar	-5.2 (16.3) (-10.7 to 0.4)	-5.4 (11.9) (-10.4 to -0.4)	-2.2 (10.3) (-7.0 to 2.6)	0.506	0.605	-	NR

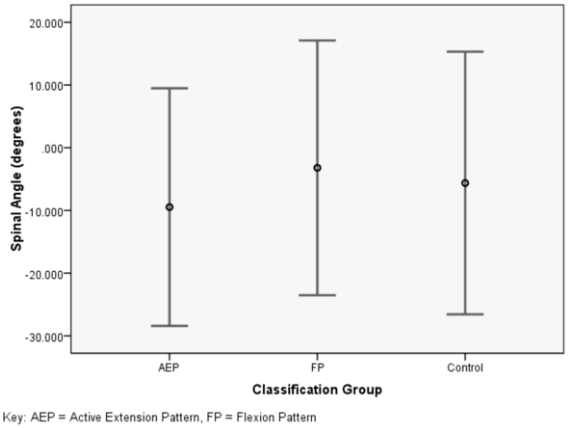
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni) (Exceptions: ‡ = except Lower Lumbar n=26, Upper Lumbar n=25

Total thoracic spine during pick up pen (bend)



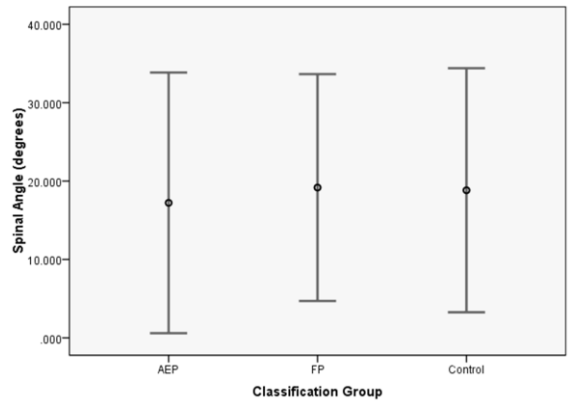
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during pick up pen (bend)



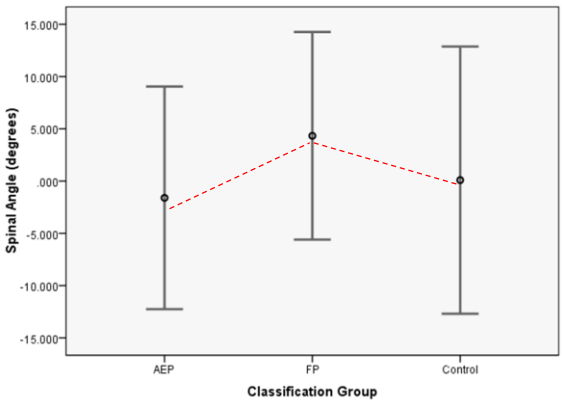
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during pick up pen (bend)



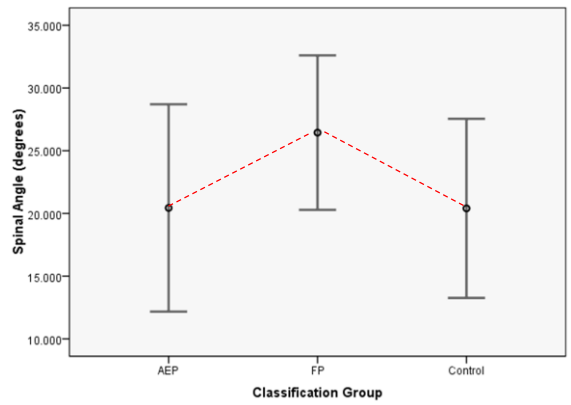
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during pick up pen (bend)



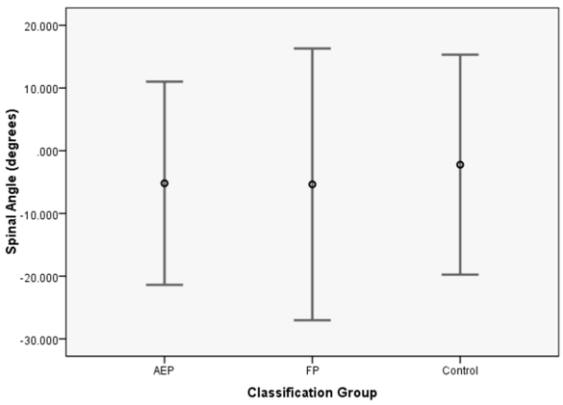
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during pick up pen (bend)



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during pick up pen (bend)



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 34: Pick Up Pen (Bend Down): Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)

Total Spinal Angles – Pick Up Pen (Bend Down)

No significant between group differences in spinal angle were observed in the total thoracic or total lumbar spinal region.

Regional Spinal Angles – Pick Up Pen (Bend Down)

Significant differences were observed between the FP and AEP groups in the upper lumbar spine ($p=0.005$) and lower thoracic spine ($p=0.033$). In both instances the FP group operated in greater flexion compared with the AEP group. In both the upper lumbar and lower thoracic spinal regions, a similar pattern of significantly increased flexion in the FP group when compared with the healthy control group was notable in each region ($p=0.018$, $p=0.044$ respectively). No significant differences were observed in either the upper thoracic or lower lumbar spinal regions. No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

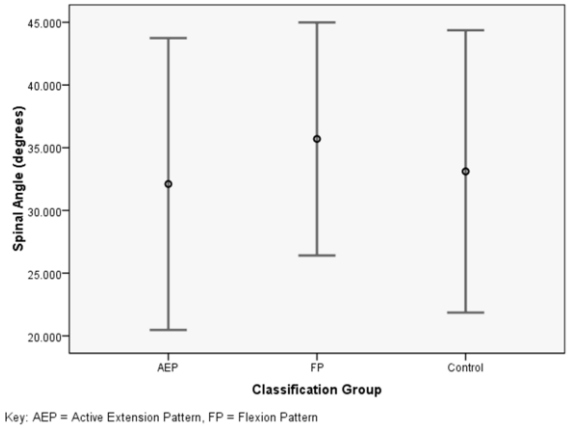
7.4.5.9 Pick Up Pen (Return)

Table 34: Descriptive and inferential statistics, post-hoc testing and hypothesis testing for the pick up pen (return) task between the active extension pattern, flexion pattern and healthy control groups

Posture	Spinal region	Classification Group Descriptives (degrees) Mean (SD) (95% CI)			One-way ANOVA (p<0.05)		Post-hoc Bonferroni test (p<0.05)	Null Hypothesis (NR=not rejected, R=rejected)
		AEP n=21	FP n=27‡	Healthy control n=28	F	p		
Pick Up Pen (Return)	Total Thoracic	32.1 (13.3) (27.4 to 36.8)	35.7 (9.4) (31.5 to 39.9)	33.1 (10.1) (29.0 to 37.2)	0.728	0486	-	NR
	Total Lumbar	-10.0 (7.7) (-14.6 to -5.5)	-3.0 (12.6) (-7.1 to 1.0)	-4.8 (10.2) (-8.8 to -0.9)	2.744	0.071	-	NR
	Upper Thoracic	14.3 (11.5) (10.1 to 18.5)	15.1 (8.5) (11.4 to 18.8)	15.6 (9.1) (-11.9 to 19.2)	0.099	0.905	-	NR
	Lower Thoracic	19.0 (8.7) (15.7 to 22.2)	25.0 (6.1) (22.2 to 27.9)	19.3 (7.6) (16.5 to 22.1)	5.478	0.006*	AEP vs. FP: 0.019* AEP vs. Healthy control: 1.000 FP vs. Healthy control: 0.016*	R
	Upper Lumbar	-1.9 (7.3) (-4.6 to 0.8)	3.9 (6.2) (1.4 to 6.4)	1.1 (5.4) (-1.2 to 3.5)	4.978	0.009*	AEP vs. FP: 0.007* AEP vs. Healthy control: 0.291 FP vs. Healthy control: 0.324	R
	Lower Lumbar	-5.3 (15.2) (-10.8 to 0.2)	-4.8 (13.1) (-9.8 to 0.2)	-2.5 (10.0) (-7.3 to 2.3)	0.360	0.699	-	NR

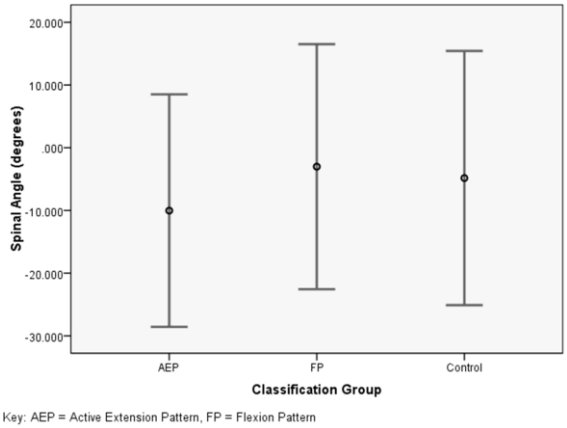
Key: SD=Standard Deviation, 95% CI = 95% confidence interval, AEP= active extension pattern motor control impairment, FP=flexion pattern motor control impairment, *significant at p<0.05 (ANOVA), p<0.05 (Post-hoc Bonferroni) (Exceptions: ‡ = except Lower Lumbar n=26, Upper Lumbar n=25)

Total thoracic spine during pick up pen (return)



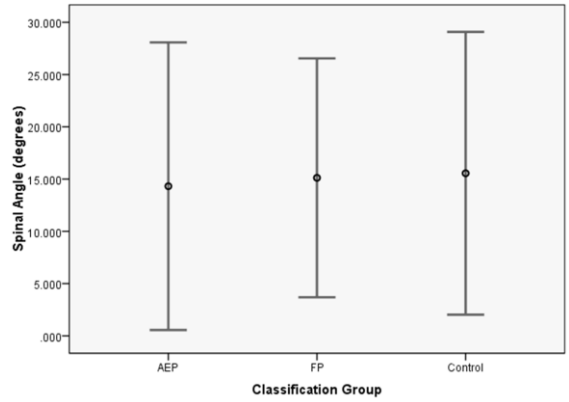
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Total lumbar spine during pick up pen (return)



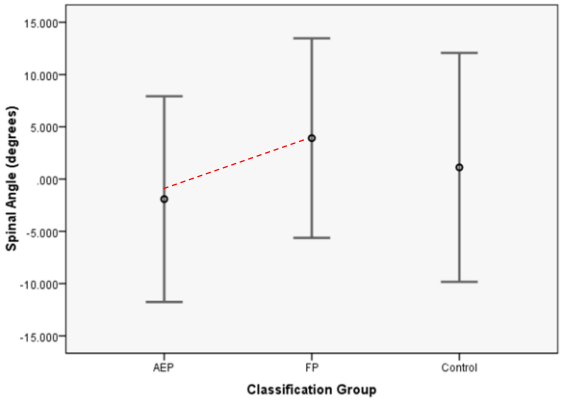
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper thoracic spine during pick up pen (return)



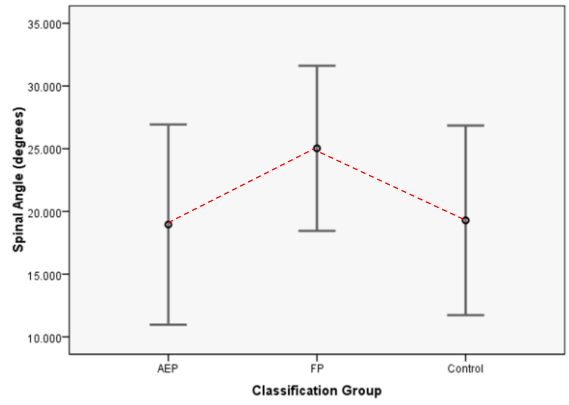
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Upper lumbar spine during pick up pen (return)



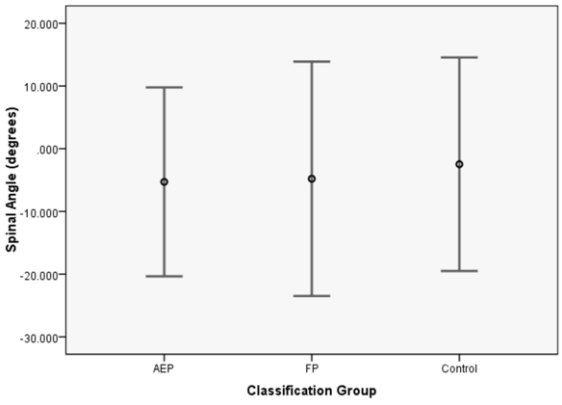
Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower thoracic spine during pick up pen (return)



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Lower lumbar spine during pick up pen (return)



Key: AEP = Active Extension Pattern, FP = Flexion Pattern

Figure 35: Pick Up Pen (Return): Max-Midpoint-Min graphs for active extension pattern, flexion pattern and healthy control groups across six spinal segments (NB: Max = Maximum Flexion, Min = Maximum Extension)

Total Spinal Angles – Pick Up Pen (Return)

No significant between group differences in spinal angle were observed in the total thoracic or total lumbar spinal region.

Regional Spinal Angles – Pick Up Pen (Return)

Significant differences were only observed between the FP and AEP groups in the upper lumbar spine ($p=0.007$) and lower thoracic spine ($p=0.019$). In both instances the FP group operated in greater flexion compared with the AEP group. In both the upper lumbar and lower thoracic spinal regions, a similar pattern of significantly increased flexion in the FP group when compared with the healthy control group was notable in the lower thoracic spine ($p=0.016$). No significant differences were observed in either the upper thoracic or lower lumbar spinal regions. No significant between groups differences between the AEP and healthy control groups were observed in any total or regional spinal segment.

7.4.5.10 Tasks: Significant Findings

All functional tasks demonstrated significant differences in the upper lumbar region between the FP and AEP groups with the FP group consistently operating in greater flexion compared to the AEP group in this spinal region across tasks. The lower thoracic spine was also found to demonstrate significant differences between these NSCLBP groups (AEP vs. FP) in all tasks, with the exception of the reach up task. No significant differences were observed in the total thoracic, upper thoracic or lower lumbar spinal regions in any functional task. Additionally significance was reached between the FP and AEP groups in the total lumbar spine during the step down, stand-to-sit and sit-to-stand tasks. Interestingly significant differences were also observed in some spinal regions with regard to the FP group when compared with the healthy control group. This phenomena occurred in the upper lumbar region during the step down, step up, box replace and pick up pen (bend down) tasks. In the lower thoracic region these differences were observed during the stand-to-sit, sit-to-stand, pick up pen (bend down) and pick up pen (return) tasks.

For all tasks the null hypothesis was not rejected for the total thoracic, upper thoracic and lower lumbar regions that there was no difference in regional sagittal spinal angles between MCI subgroups of NSCLBP subjects and healthy controls. The null hypothesis was rejected in the upper lumbar spine, for all tasks and in the lower thoracic spine for all tasks (with the exception of reach up), to conclude that there was a difference in sagittal spinal angles between MCI subgroups of NSCLBP subjects in these spinal regions during these tasks. Additionally for stand-to-sit the null hypothesis was also rejected.

The null hypothesis was only not rejected for the box lift and reach up tasks with regard to differences between the healthy control group and NSCLBP subgroups, as these were the only tasks in which no significant differences between the healthy control group and either of the NSCLBP subgroups were observed in any spinal region.

7.4.6 Kinematics: Significant Findings

Table 35 summarises the regional significant differences observed in each task. It is clear that significant differences were observed primarily in the upper lumbar and lower thoracic spinal regions. In the upper lumbar region significant differences were observed between the AEP and FP groups, during all tasks, postures and ROM tasks, with exception of full extension. In the lower thoracic spine significant differences were observed between the AEP and FP groups during all tasks except reach up. Additionally these differences were also observed during usual sitting.

Differences were also observed between the FP and healthy control groups in the lower thoracic region during usual sitting, stand-to-sit, sit-to-stand, pick up pen (bend down) and pick up pen (return) tasks. These differences were also observed in the upper lumbar region in both postures (usual standing and sitting), step down, step up, box replace and pick up pen (bend down) tasks. Significance was achieved in the total lumbar spine (between the FP and AEP groups) in the usual sitting posture, full flexion, step down, stand-to-sit and the sit-to-stand tasks only.

The only significant differences observed in the upper thoracic region occurred during full extension between the FP and AEP groups, where interestingly this was the only occurrence of a reversal of the expected posture type, with the FP group adopting a significantly more extended spinal posture in this region. No differences were observed in the total thoracic or lower lumbar spinal regions during any posture, ROM or task.

	Total Thoracic	Total Lumbar	Upper Thoracic	Lower Thoracic	Upper Lumbar	Lower Lumbar
Posture						
Usual Standing					*[*]	
Usual Sitting		*		* [*]	*[*]	
Range of Movement						
Flexion		*			*	
Extension			*			
Task						
Reach Up					*	
Step Down		*		*	*[*]	
Step Up				*	*[*]	
Box Replace				*	*[*]	
Box Lift				*	*	
Stand-to-Sit		*		*[*]	*	
Sit-to-Stand		*		*[*]	*	
Pick Up Pen (Bend Down)				*[*]	*[*]	
Pick Up Pen (Return)				*[*]	*	

Key: * = Significant difference ($p<0.05$) between FP group and AEP group, [*] = Significant difference ($p<0.05$) between FP group and healthy control group

7.4.6.1 Consideration of gender as a covariate

Since a difference in gender distribution was noted between the groups (Table 13), one-way ANOVAs with gender as a covariate (post-hoc Bonferroni testing) were run to evaluate the impact of gender on the results observed. The summarised findings are presented in Table 36.

Fewer significant findings were observed once gender was accounted for with no significant differences observed in the total thoracic, total lumbar, upper thoracic or lower lumbar regions during any postures, ROM or functional tasks. Similarly no significant differences were observed in any spinal region during usual standing, extension, reach up, step up or the box lift tasks. However a number of results narrowly missed significance between the FP and AEP groups: usual standing in the lower thoracic region ($p=0.054$), step up in the lower thoracic region ($p=0.051$), box lift in both the lower thoracic ($p=0.063$) and upper lumbar regions ($p=0.062$) and sit-to-stand in the upper lumbar region ($p=0.061$). Similarly differences between the FP and control groups narrowly missed significance in the lower thoracic region during sit to stand ($p=0.057$).

Table 36: Kinematics - Summary of significant between group results (p<0.05) for all activities in each spinal region with gender as a covariate

	Total Thoracic	Total Lumbar	Upper Thoracic	Lower Thoracic	Upper Lumbar	Lower Lumbar
Posture						
Usual Standing						
Usual Sitting				* *	*	
Range of Movement						
Flexion					*	
Extension						
Task						
Reach Up						
Step Down				*		
Step Up				*		
Box Replace				*	*	
Box Lift						
Stand-to-Sit					*	
Sit-to-Stand				*		
Pick Up Pen (Bend Down)				**		
Pick Up Pen (Return)				**		

Key: * = Significant difference (p<0.05) between FP group and AEP group, * = Significant difference (p<0.05) between FP group and healthy control group

7.5 Surface Electromyography

The sEMG results section reports the within-day reliability (ICC) of the mean normalised amplitude sEMG across 3 trials for each of the functional tasks, followed by the results for the between-group mean normalised sEMG amplitude during each functional task.

Missing Data

For the sEMG trials only trials with good quality data recording were used. Thus a smaller sample was included in the final analysis due to calculation error and poor data quality. The final numbers of subject data used in each analysis is outlined in Table 39 and Table 40.

Outliers

All variables were plotted on a scatterplot and any visual outliers identified. Box plots for each variable, split by group (AEP, FP and healthy control), were then obtained. Where the normalised amplitude for the motor unit potential appeared substantially abnormal following visual inspection, the trial was omitted from the final analysis (Stalberg et al. 1994).

7.5.1 sEMG – Within-Day Reliability

sEMG was recorded bilaterally (left and right) for each muscle group. Paired t-tests were conducted as a preliminary analysis for all functional tasks (Appendix IX) which revealed significant differences between left and right muscle groups with no consistent pattern emerging. Thus right and left musculature was evaluated independently (Svendsen et al. 2013).

Tables 37 and 38 depict the ICC, 95% confidence intervals and standard error of measurement (SEM) for the normalised (%SMVC) right (Table 37) and left (Table 38) normalised amplitude sEMG values during functional tasks. The measurements are taken from 3 consecutive trials and compared between the AEP, FP and healthy control groups.

Table 37: Within-day reliability for right normalised amplitude sEMG (%SMVC) during functional tasks

		TrA/IO	EO	sLM	LT
Step Down	AEP	0.840 (0.704 to 0.926) 12.8	0.855 (0.732 to 0.931) 10.7	0.736 (0.568 to 0.891) 16.5	0.300 (-0.003 to 0.627) 18.1
	FP	0.685 (0.440 to 0.859) 27.7	0.941 (0.879 to 0.975) 6.1	0.611 (0.357 to 0.810) 16.4	0.573 (0.316 to 0.782) 12.8
	Control	0.798 (0.629 to 0.906) 14.8	0.915 (0.828 to 0.963) 6.0	0.266 (0.015 to 0.544) 15.6	0.326 (0.064 to 0.599) 14.5
Step Up	AEP	0.831 (0.688 to 0.921) 12.6	0.882 (0.778 to 0.945) 8.9	0.897 (0.792 to 0.957) 6.5	0.934 (0.859 to 0.973) 6.8
	FP	0.811 (0.626 to 0.923) 17.2	0.963 (0.922 to 0.984) 4.7	0.799 (0.626 to 0.910) 11.6	0.773 (0.578 to 0.899) 9.1
	Control	0.839 (0.701 to 0.925) 11	0.944 (0.885 to 0.976) 4.6	0.615 (0.387 to 0.796) 6	0.559 (0.312 to 0.764) 7.3
Reach Up	AEP	0.833 (0.670 to 0.930) 11.6	0.867 (0.741 to 0.942) 8.4	0.901 (0.795 to 0.960) 6.1	0.563 (0.270 to 0.798) 8.6
	FP	0.863 (0.712 to 0.947) 14.8	0.897 (0.786 to 0.958) 8.2	0.779 (0.572 to 0.908) 12.8	0.878 (0.751 to 0.950) 6.8
	Control	0.890 (0.789 to 0.950) 10.4	0.961 (0.918 to 0.984) 3.9	0.509 (0.247 to 0.737) 6.2	0.657 (0.430 to 0.828) 6.4
Pick Up Pen (Bend Down)	AEP	0.879 (0.762 to 0.947) 11.5	0.814 (0.649 to 0.916) 12.1	0.809 (0.636 to 0.917) 12	0.482 (0.177 to 0.750) 10.7
	FP	0.919 (0.825 to 0.968) 11.3	0.947 (0.888 to 0.978) 6.1	0.941 (0.873 to 0.976) 6.5	0.867 (0.741 to 0.942) 7.1
	Control	0.940 (0.887 to 0.972) 7.3	0.919 (0.843 to 0.964) 5.6	0.492 (0.241 to 0.716) 9	0.748 (0.573 to 0.871) 6.6
Pick Up Pen (Return)	AEP	0.911 (0.821 to 0.962) 10.1	0.824 (0.662 to 0.924) 11.7	0.889 (0.777 to 0.953) 8.1	0.391 (0.082 to 0.692) 13
	FP	0.916 (0.819 to 0.967) 12.3	0.954 (0.902 to 0.981) 5.5	0.968 (0.929 to 0.987) 4.9	0.893 (0.788 to 0.954) 6.1
	Control	0.901 (0.817 to 0.952) 9.8	0.947 (0.894 to 0.976) 4.3	0.611 (0.382 to 0.793) 7.8	0.692 (0.494 to 0.839) 6.3
Stand to Sit	AEP	0.365 (0.082 to 0.649) 34.8	0.811 (0.646 to 0.915) 9.7	0.891 (0.771 to 0.957) 9.3	0.469 (0.152 to 0.751) 11.4
	FP	0.893 (0.791 to 0.952) 14.1	0.955 (0.912 to 0.979) 5.2	0.930 (0.864 to 0.968) 6.2	0.907 (0.822 to 0.957) 5.4
	Control	0.782 (0.610 to 0.896) 16.2	0.830 (0.677 to 0.924) 7.7	0.677 (0.463 to 0.836) 4.9	0.829 (0.693 to 0.917) 4.2
Sit to Stand	AEP	0.397 (0.113 to 0.672) 34.1	0.864 (0.730 to 0.942) 8.6	0.914 (0.816 to 0.966) 8.2	0.335 (0.019 to 0.663) 14
	FP	0.867 (0.745 to 0.940) 14.7	0.945 (0.895 to 0.975) 5.8	0.936 (0.875 to 0.970) 6.1	0.815 (0.667 to 0.911) 7.7
	Control	0.914 (0.833 to 0.961) 8.5	0.925 (0.848 to 0.968) 5.3	0.649 (0.431 to 0.817) 6.4	0.783 (0.621 to 0.893) 4.5
Box Replace	AEP	0.869 (0.749 to 0.941) 10.9	0.861 (0.742 to 0.934) 9.5	0.580 (0.317 to 0.791) 23.6	0.309 (0.013 to 0.624) 15.7
	FP	0.797 (0.617 to 0.911) 19	0.968 (0.935 to 0.986) 4.3	0.756 (0.569 to 0.882) 13.2	0.790 (0.621 to 0.900) 9.2
	Control	0.715 (0.515 to 0.858) 17.3	0.848 (0.708 to 0.933) 7.5	0.247 (-0.003 to 0.528) 12.5	0.192 (-0.55 to 0.486) 16.5
Box Lift	AEP	0.867 (0.744 to 0.940) 10.7	0.849 (0.722 to 0.929) 9.7	0.929 (0.850 to 0.972) 5.1	0.753 (0.547 to 0.889) 13.4
	FP	0.852 (0.709 to 0.936) 14.3	0.936 (0.874 to 0.972) 5.8	0.796 (0.632 to 0.904) 11.8	0.905 (0.817 to 0.957) 5.2
	Control	0.743 (0.557 to 0.873) 17.5	0.926 (0.850 to 0.968) 5.2	0.602 (0.371 to 0.788) 6.3	0.436 (0.167 to 0.687) 7.5

Key: TrA/IO = transversus abdominis / internal obliques, EO = external obliques, sLM = superficial lumbar multifidus, ES = erector spinae (thoracic), AEP = active extension pattern motor control impairment, FP = flexion pattern motor control impairment, ICC = Interclass Correlation Coefficient, SEM = Standard Error of Measurement (degrees)

Table 38: Within-day reliability for left normalised amplitude sEMG (%SMVC) during functional tasks

		TrA/IO	EO	sLM	LT
Step Down	AEP	0.627 (0.376 to 0.818) 22.5	0.843 (0.682 to 0.937) 12.7	0.289 (0.011 to 0.591) 21.4	0.318 (0.013 to 0.640) 21.3
	FP	0.542 (0.292 to 0.754) 37.5	0.876 (0.751 to 0.947) 9.4	0.358 (0.083 to 0.637) 18.6	0.309 (0.042 to 0.592) 21.2
	Control	0.516 (0.249 to 0.747) 29.5	0.939 (0.879 to 0.973) 5.5	0.148 (-0.092 to 0.444) 17.2	0.338 (0.076 to 0.609) 19.4
Step Up	AEP	0.766 (0.574 to 0.893) 16	0.876 (0.743 to 0.951) 9.3	0.905 (0.806 to 0.960) 4.3	0.526 (0.226 to 0.777) 12.7
	FP	0.688 (0.466 to 0.849) 17.5	0.928 (0.851 to 0.970) 7.2	0.797 (0.628 to 0.906) 9.3	0.814 (0.660 to 0.912) 7.4
	Control	0.468 (0.188 to 0.721) 27.7	0.970 (0.940 to 0.987) 3.9	0.631 (0.402 to 0.809) 5.1	0.816 (0.667 to 0.912) 7.1
Reach Up	AEP	0.405 (0.085 to 0.710) 35.1	0.660 (0.373 to 0.861) 14.7	0.785 (0.597 to 0.905) 7	0.714 (0.438 to 0.891) 5.8
	FP	0.815 (0.632 to 0.924) 23	0.936 (0.861 to 0.975) 6.8	0.801 (0.624 to 0.913) 9.2	0.767 (0.562 to 0.899) 9.4
	Control	0.589 (0.336 to 0.792) 25.4	0.913 (0.822 to 0.964) 6.4	0.358 (0.083 to 0.637) 9.4	0.511 (0.250 to 0.738) 12.1
Pick Up Pen (Bend Down)	AEP	0.625 (0.348 to 0.832) 24	0.826 (0.652 to 0.929) 14.8	0.861 (0.726 to 0.941) 5.8	0.468 (0.126 to 0.769) 9
	FP	0.890 (0.774 to 0.955) 16.6	0.761 (0.544 to 0.900) 14.2	0.954 (0.904 to 0.980) 4.3	0.818 (0.651 to 0.921) 8.3
	Control	0.580 (0.337 to 0.778) 35.7	0.933 (0.867 to 0.970) 5.2	0.459 (0.210 to 0.688) 8.2	0.565 (0.331 to 0.761) 9.6
Pick Up Pen (Return)	AEP	0.561 (0.278 to 0.791) 36.9	0.811 (0.625 to 0.922) 17.1	0.795 (0.614 to 0.910) 7.4	0.615 (0.299 to 0.846) 6.8
	FP	0.859 (0.717 to 0.942) 18.8	0.785 (0.582 to 0.911) 14	0.946 (0.889 to 0.977) 4.6	0.841 (0.690 to 0.931) 8.3
	Control	0.594 (0.349 to 0.791) 35	0.955 (0.910 to 0.980) 4.5	0.627 (0.403 to 0.804) 5.8	0.836 (0.708 to 0.919) 6
Stand to Sit	AEP	0.588 (0.301 to 0.812) 34.1	0.749 (0.524 to 0.894) 16.2	0.594 (0.308 to 0.815) 6.2	0.377 (0.035 to 0.714) 9.9
	FP	0.848 (0.717 to 0.930) 18.5	0.641 (0.403 to 0.823) 19.1	0.891 (0.797 to 0.948) 5.8	0.720 (0.528 to 0.858) 11.2
	Control	0.332 (0.043 to 0.632) 32.3	0.908 (0.821 tob 0.958) 6.4	0.445 (0.190 to 0.683) 8.6	0.602 (0.371 to 0.788) 10.2
Sit to Stand	AEP	0.663 (0.399 to 0.852) 28.2	0.818 (0.637 to 0.925) 14	0.781 (0.575 to 0.909) 4.6	0.484 (0.156 to 0.768) 17.1
	FP	0.875 (0.763 to 0.943) 17.1	0.769 (0.585 to 0.892) 13.9	0.933 (0.872 to 0.969) 5	0.731 (0.544 to 0.864) 10.2
	Control	0.329 (0.032 to 0.639) 32.1	0.822 (0.673 to 0.916) 10.1	0.809 (0.657 to 0.908) 3.9	0.683 (0.477 to 0.837) 8.5
Box Replace	AEP	0.698 (0.466 to 0.861) 22.4	0.772 (0.568 to 0.901) 16.1	0.416 (0.125 to 0.693) 18.7	0.191 (-0.095 to 0.539) 22.2
	FP	0.673 (0.463 to 0.831) 28.9	0.687 (0.471 to 0.845) 15	0.764 (0.587 to 0.884) 10.1	0.608 (0.372 to 0.795) 13
	Control	0.456 (0.189 to 0.701) 26.3	0.820 (0.670 to 0.916) 9.3	0.388 (0.118 to 0.653) 9.7	0.297 (0.031 to 0.583) 19.3
Box Lift	AEP	0.544 (0.274 to 0.770) 34.3	0.833 (0.671 to 0.930) 12.5	0.386 (0.103 to 0.664) 18.4	0.316 (0.011 to 0.639) 18.3
	FP	0.796 (0.641 to 0.900) 19.2	0.756 (0.570 to 0.883) 12.6	0.748 (0.564 to 0.876) 10.5	0.652 (0.429 to 0.821) 10.5
	Control	0.522 (0.269 to 0.741) 31	0.890 (0.789 to 0.950) 7	0.788 (0.623 to 0.897) 3.8	0.652 (0.429 to 0.821) 10.1

Key: TrA/IO = transversus abdominis / internal obliques, EO = external obliques, sLM = superficial lumbar multifidus, ES = erector spinae (thoracic), AEP = active extension pattern motor control impairment, FP = flexion pattern motor control impairment, ICC = Interclass Correlation Coefficient, SEM = Standard Error of Measurement (degrees)

Mean normalised amplitude sEMG for each group during each task across the three repeated trials demonstrated varied test re-test reliability with ICC values ranging from poor (0.191) to almost perfect (0.970) (Landis and Koch 1977). Across all muscle groups and tasks the reliability (right and left) was varied with 0.191 to 0.934, 0.309 to 0.968 and 0.192 to 0.970 for the AEP, FP and healthy control groups respectively. Similarly SEM values were also wide ranging across groups: AEP 4.3 to 36.9, FP 4.3 to 37.5, and healthy control 3.8 to 35.7. Although these results are similar between groups, the wide variation in SEM indicates that the degree of error of measurement showed a wide variability with regard to performance.

When each muscle group was considered independently the EO muscles demonstrated good to excellent test re-test reliability (ICC 0.641 to 0.970, SEM 3.9 to 19.1). TrA/IO showed more moderate reliability estimates (ICC 0.329 to 0.940), however due to the high SEM values (7.3 to 37.5) the findings must be treated with caution. Great variation in reliability scores was also observed in both the extensor muscle groups with the sLM and LT muscles demonstrating ICC values varying from poor to excellent across tasks (0.247 to 0.968, and 0.191 to 0.934 respectively). The SEM values for the sLM ranged from 3.8 to 23.6 and 4.2 to 22.2 for the LT muscles.

This variance was also evident between the right (ICC 0.192 to 0.968) and left musculature (ICC 0.191 to 0.970). For the right musculature, 87% of the ICC results for all groups and tasks were found to be greater than 0.5, indicating moderate to excellent overall within-day reliability for the mean normalised amplitude of sEMG (Landis and Koch 1977). This was slightly lower for the left musculature (81.6%) however these results suggest that calculation of average normalised sEMG values across three trials appears to provide a broadly representative measure of the subjects muscle activity behaviour during these functional tasks, although some caution should be applied when interpreting results.

7.5.2 sEMG – Tasks

Tables 39 and 40 show the descriptive and inferential statistics for the results of the normalised (%SMVC) mean normalised amplitude sEMG results of the right (Table 39) and left (Table 40) musculature during the series of functional tasks for all three groups; AEP, FP, and healthy control.

7.5.2.1 Right Muscle Activity

Kruskal-Wallis tests of the right-sided muscle activity revealed no significant between group differences in the TrA/IO or LT muscles during any functional task. Right sided sLM activity was

found to be significantly different during step up (p=0.015), reach up (p=0.013) and box replace (p=0.007) tasks between the AEP and healthy control groups, with the AEP group demonstrating significantly greater activity compared to the healthy control subjects. Interestingly, right EO activity was identified to be significantly different between the AEP and healthy control groups during the box lift (p=0.016) task, with the AEP group demonstrating significantly greater activity compared to the healthy control subjects. With regard to right EO and right sLM muscle activity, evaluation of the mean values shows that the general trend between groups is for both the AEP and FP groups to display increased muscle activity levels compared with the healthy control group, however the AEP group consistently present with the highest activity recordings and demonstrated significant differences with the healthy control group. Although the FP group demonstrate values that appear to consistently be greater than those of the healthy control group, these differences were not found to be significantly different.

7.5.2.2 Left Muscle Activity

Kruskal-Wallis tests of the left sided muscle activity revealed no significant between group differences in the EO or LT muscles during any functional task. Although the Kruskal-Wallis test showed left sided TrA/IO activity to be significant ($p=0.044$, $p<0.05$) during the sit-to-stand task, following post-hoc Mann-Whitney U testing no significant between group differences were observed with the AEP and healthy control group differences only reaching a significance level of 0.056 and the FP and control group reaching a significance level of 0.023. Left sLM was only found to be significantly greater in the FP compared to the healthy group during the stand to sit task (p=0.009). A non-significant difference was noted between the AEP group and healthy group in the sLM during this task (p=0.030 p>0.0167)). Interestingly, in contrast to the right sided muscle activity results, significant between group differences were observed in the Left TrA/IO during the stand-to-sit (p=0.009) between the FP and healthy control groups, with the FP groups demonstrating significantly increased TrA/IO activity compared to the healthy control group. No other between group differences were observed in any functional task.

Table 39: Mean, standard deviation (SD), Kruskal-Wallis and post-hoc Mann-Whitney U results and hypothesis testing for normalized (%SMVC) amplitude EMG of the right musculature during functional tasks (active extension pattern, flexion pattern and healthy control groups)

Task	Muscle	AEP		FP		Control		Kruskal-Wallis (*p<0.05)	Mann Whitney-U Pairwise comparisons (post hoc) (*p<0.0167)	Not Reject / Reject Null Hypothesis
		Number of trials	Mean (SD)	Number of trials	Mean (SD)	Number of trials	Mean (SD)			
Step Down	IO	21	57.4 (32.3)	21	62.3 (34.5)	25	52.6 (32.6)	0.576	-	NR
	EO	21	54.4 (26.8)	24	46.2 (23.9)	22	38.8 (21.2)	0.109	-	NR
	sLM	20	33.8 (32.2)	22	24.6 (23.6)	25	16.2 (10.7)	0.136	-	NR
	LT	18	25.8 (20.6)	22	26.2 (17.7)	26	26.9 (24.5)	0.937	-	NR
Step Up	IO	21	55.1 (31.4)	21	65.0 (39.0)	25	51.1 (33.4)	0.419	-	NR
	EO	21	53.8 (25.0)	24	46.8 (25.0)	22	36.8 (19.7)	0.059	-	NR
	sLM	20	33.8 (33.8)	22	25.0 (24.8)	25	14.6 (9.7)	0.046*	FP vs AEP: 0.227 FP vs Control: 0.179 AEP vs Control: 0.015*	R
	LT	18	26.7 (21.0)	22	26.2 (19.2)	26	25.8 (27.9)	0.547	-	NR
Reach Up	IO	23	50.2 (25.0)	20	63.6 (36.8)	25	50.2 (35.2)	0.284	-	NR
	EO	23	50.7 (23.1)	24	44.2 (23.7)	22	36.7 (19.7)	0.108	-	NR
	sLM	20	26.9 (25.2)	22	19.4 (23.1)	26	12.9 (8.7)	0.039*	FP vs AEP: 0.062 FP vs Control: 0.694 AEP vs Control: 0.013*	R
	LT	19	26.7 (26.2)	22	22.7 (16.0)	26	21.1 (16.6)	0.698	-	NR
Pick Up Pen (Bend Down)	IO	21	54.1 (34.3)	20	64.1 (38.0)	26	50.0 (31.1)	0.391	-	NR
	EO	21	50.2 (23.8)	24	43.9 (25.7)	21	35.0 (17.8)	0.101	-	NR
	sLM	18	28.4 (26.4)	23	20.0 (23.6)	24	16.3 (12.8)	0.132	-	NR
	LT	18	25.6 (21.5)	23	24.0 (18.5)	26	23.6 (19.0)	0.827	-	NR
Pick Up Pen (Return)	IO	21	54.9 (34.5)	20	62.3 (37.4)	25	48.5 (27.8)	0.45	-	NR
	EO	20	50.3 (26.4)	24	43.2 (25.2)	21	34.5 (17.8)	0.122	-	NR
	sLM	18	29.0 (24.8)	23	20.4 (22.3)	24	16.1 (10.2)	0.089	-	NR
	LT	17	26.9 (21.8)	23	24.1 (17.9)	26	24.2 (23.8)	0.625	-	NR
Stand-to-Sit	IO	22	59.7 (49.4)	18	68.3 (53.1)	24	44.3 (27.3)	0.266	-	NR
	EO	22	53.6 (25.5)	21	46.2 (24.0)	20	37.8 (20.4)	0.14	-	NR
	sLM	20	50.8 (67.8)	21	31.2 (23.6)	24	19.8 (18.3)	0.054	-	NR
	LT	17	56.3 (79.5)	22	32.1 (17.3)	24	40.8 (48.7)	0.693	-	NR
Sit-to-Stand	IO	22	58.8 (52.4)	18	55.1 (34.8)	23	42.1 (27.6)	0.381	-	NR
	EO	22	51.5 (24.9)	21	44.6 (23.2)	21	44.0 (37.6)	0.259	-	NR
	sLM	19	44.9 (76.9)	21	23.0 (24.9)	23	12.5 (7.1)	0.254	-	NR
	LT	18	27.7 (22.3)	22	23.5 (15.7)	24	33.5 (47.8)	0.523	-	NR
Box Replace	IO	23	61.2 (41.8)	20	69.3 (44.2)	25	52.3 (37.5)	0.453	-	NR
	EO	23	55.5 (25.6)	23	44.4 (24.7)	21	37.8 (19.3)	0.062	-	NR
	sLM	19	33.1 (23.3)	23	22.9 (22.5)	25	17.1 (11.1)	0.026*	FP vs AEP: 0.056 FP vs Control: 0.642 AEP vs Control: 0.007*	R
	LT	19	33.5 (26.9)	22	24.6 (16.8)	25	27.1 (28.7)	0.486	-	NR
Box Lift	IO	23	61.3 (42.1)	20	69.7 (44.9)	25	52.0 (38.2)	0.349	-	NR
	EO	23	57.6 (25.6)	23	43.8 (23.4)	21	37.5 (19.1)	0.019	FP vs AEP: 0.057 FP vs Control: 0.296 AEP vs Control: 0.008*	R
	sLM	19	32.9 (22.5)	23	24.6 (24.3)	25	18.4 (12.0)	0.051	-	NR
	LT	18	31.9 (25.5)	22	25.3 (16.6)	25	29.0 (32.7)	0.469	-	NR

Table 40: Mean, standard deviation (SD), (SD), Kruskal-Wallis and post-hoc Mann-Whitney U results and hypothesis testing for normalized (%SMVC) normalised amplitude EMG of the left musculature during functional tasks (active extension pattern, flexion pattern and healthy control groups)

Task	Muscle	AEP		FP		Control		Kruskal-Wallis (*p<0.05)	Mann-Whitney U Pairwise Comprisons (Post hoc) (*p<0.0167)	Not Reject / Reject Null Hypothesis
		Number of trials	Mean (SD)	Number of trials	Mean (SD)	Number of trials	Mean (SD)			
Step Down	IO	21	78.8 (50.2)	24	74.7 (42.1)	25	76.3 (51.9)	0.948	-	NR
	EO	19	61.5 (39.7)	21	54.3 (22.7)	23	44.7 (23.4)	0.249	-	NR
	sLM	20	19.8 (14.8)	23	19.9 (17.7)	25	13.6 (9.1)	0.287	-	NR
	LT	16	22.7 (12.3)	23	22.7 (15.5)	25	22.8 (12.3)	0.933	-	NR
Step Up	IO	21	79.4 (55.4)	24	78.9 (43.5)	25	74.7 (58.0)	0.69	-	NR
	EO	19	60.5 (34.3)	21	54.7 (24.0)	23	42.6 (21.9)	0.1	-	NR
	sLM	20	20.2 (16.2)	23	19.7 (18.6)	25	12.7 (8.7)	0.218	-	NR
	LT	16	22.8 (10.9)	23	21.8 (15.3)	25	22.6 (13.3)	0.777	-	NR
Reach Up	IO	22	70.1 (55.9)	23	71.8 (40.4)	23	58.8 (47.0)	0.229	-	NR
	EO	19	52.6 (34.2)	21	53.2 (24.6)	23	41.9 (20.8)	0.252	-	NR
	sLM	20	19.6 (14.3)	23	19.0 (19.0)	25	13.6 (8.4)	0.38	-	NR
	LT	18	28.6 (17.2)	21	20.2 (15.5)	25	23.4 (14.8)	0.173	-	NR
Pick Up Pen (Bend Down)	IO	18	77.2 (60.4)	22	73.5 (46.1)	24	76.6 (52.6)	0.957	-	NR
	EO	18	56.6 (33.3)	21	56.8 (32.0)	23	42.2 (20.8)	0.277	-	NR
	sLM	18	25.1 (37.9)	23	18.8 (18.3)	24	14.5 (8.7)	0.812	-	NR
	LT	14	29.6 (36.7)	23	20.5 (15.7)	24	22.4 (13.2)	0.626	-	NR
Pick Up Pen (Return)	IO	18	75.4 (57.4)	22	74.6 (47.3)	21	64.8 (31.9)	0.869	-	NR
	EO	18	56.9 (3.8)	21	55.4 (31.0)	23	43.9 (22.3)	0.379	-	NR
	sLM	18	25.2 (37.2)	23	18.4 (18.1)	24	14.0 (8.4)	0.624	-	NR
	LT	14	29.2 (35.7)	23	20.9 (16.7)	24	22.1 (12.8)	0.572	-	NR
Stand-to-Sit	IO	18	60.0 (40.0)	23	76.5 (54.2)	22	39.5 (23.7)	0.02*	FP vs AEP: 0.281 FP vs Control: 0.009* AEP vs Control:0.061	R
	EO	17	58.4 (36.9)	21	55.3 (23.4)	22	40.6 (22.2)	0.094	-	NR
	sLM	19	30.9 (20.8)	22	28.7 (17.1)	22	17.6 (15.4)	0.02*	FP vs AEP: 0.875 FP vs Control: 0.009* AEP vs Control: 0.030	R
	LT	15	45.0 (32.0)	22	33.2 (22.4)	23	38.6 (29.9)	0.427	-	NR
Sit-to-Stand	IO	19	56.0 (35.0)	23	62.6 (44.8)	23	36.7 (21.8)	0.044*	FP vs AEP: 0.587 FP vs Control: 0.023 AEP vs Control: 0.056	NR
	EO	17	52.6 (29.5)	21	53.7 (23.4)	22	39.2 (22.0)	0.115	-	NR
	sLM	17	17.1 (13.5)	22	19.6 (19.8)	23	12.3 (7.9)	0.427	-	NR
	LT	16	29.5 (19.0)	22	22.5 (16.0)	23	28.4 (19.7)	0.301	-	NR
Box Replace	IO	22	70.5 (39.0)	24	75.8 (41.1)	24	74.1 (63.9)	0.593	-	NR
	EO	19	57.8 (33.1)	21	54.3 (24.8)	23	42.7 (20.7)	0.251	-	R
	sLM	21	23.4 (14.7)	24	21.0 (18.2)	24	15.1 (9.2)	0.132	-	NR
	LT	17	25.9 (14.6)	22	19.8 (16.2)	24	22.6 (12.9)	0.23	-	NR
Box Lift	IO	22	72.3 (39.3)	24	76.2 (42.6)	23	74.2 (60.8)	0.66	-	NR
	EO	19	60.0 (35.0)	21	55.4 (25.4)	23	42.5 (21.2)	0.129	-	NR
	sLM	21	23.6 (14.4)	24	20.5 (17.6)	24	15.1 (8.6)	0.123	-	NR
	LT	17	25.5 (13.4)	22	19.4 (15.2)	24	22.6 (13.9)	0.155	-	NR

7.5.3 sEMG: Significant Findings

Table 41: sEMG – Summary of significant between group (active extension pattern, flexion pattern and healthy control groups) results (*p<0.0167) for all trunk muscle activity in each functional task

	Right				Left			
	TrA/IO	EO	sLM	LT	TrA/IO	EO	sLM	LT
Step Down								
Step Up			*					
Reach Up			*					
Pick Up Pen (Bend)								
Pick Up Pen (Return)								
Stand-to-Sit					*		*	
Sit-to-Stand								
Box Replace			*					
Box Lift		*						

Key: TrA/IO = Transversus Abdominis / Internal Oblique, EO = External Oblique, sLM = superficial Lumbar Multifidus, LT = Longissimus Thoracis (Erector Spinae)

*= Significantly increased (p<0.0167) muscle activity in the AEP group compared to the healthy control group

*= Significantly increased (p<0.0167) muscle activity in the FP group compared to the healthy control group

Interestingly, the asymmetrical nature of the functional tasks explored were reflected in the between side difference identified with regard to muscle activity. No significant between group differences were identified in the LT musculature bilaterally during any task. TrA/IO activity was significantly increased in the FP group compared to the healthy control group during the stand-to-sit ($p=0.009$) tasks on the left side only. EO was identified to be significantly different between the AEP and healthy control groups during the box lift ($p=0.016$) task on the right side only, with the AEP group demonstrating significantly greater activity compared to the healthy control subjects. Significant between group differences were identified in the right sided sLM activity during step up ($p=0.029$), reach up ($p=0.013$) and box replace ($p=0.007$) between the AEP and healthy control groups, with the AEP group demonstrating significantly greater activity compared to the healthy control subjects. However on the left side sLM activity was significantly greater in the FP group compared to the healthy group during the stand to sit task only ($p=0.009$). No other significant differences were observed for left sLM muscle activity.

A limitation of using non-parametric testing (Kruskal-Wallis) to analyse this sEMG data is the inability to evaluate gender as a covariate. The data was also analysed using ANOVA with gender considered as a covariate. Significant between group differences were only observed to occur between the AEP and healthy group in the right sLM in the box replace task and the right EO in the box lift task; and between the FP and healthy group in the left TrA/IO musculature during the stand-to-sit task. In all instances the NSCLBP subgroup exhibited increased muscle activity compared to the healthy group.

The null hypothesis was therefore rejected for TrA/IO, EO and sLM musculature for the tasks where these muscle groups were identified to display significant differences, as for these tasks a significant difference in trunk muscle sEMG between MCI subgroups of NSCLBP subjects and healthy controls was observed. The null hypothesis was not rejected for the LT musculature for all tasks, with no difference in trunk muscle sEMG between MCI subgroups of NSCLBP subjects and healthy controls during a series of functional tasks observed.

8 DISCUSSION

This chapter will discuss the results obtained from the main study (spinal kinematics and muscle activity). The thesis also includes a Systematic Review of spinal marker sets previously utilised in optoelectronic trunk movement studies (Chapter 4) and a preliminary reliability study (Chapter 5). As the results of these studies have been previously discussed, this chapter will provide a discussion focussing on the results of the main study.

The main study of this thesis aimed to investigate between group differences in subclassified groups of NSCLBP (AEP and FP) and a healthy control group to explore potential differences in motor control parameters (spinal kinematics and trunk muscle activation) as proposed by the MDCS (O'Sullivan 2005) during a series of functional tasks. The planned between group comparisons tested specific hypotheses to investigate whether there is a difference in sagittal spinal angle between MCI subgroups (AEP and FP) and healthy controls in six spinal regions during static postures, full ROM (flexion and extension) and a series of functional tasks. A secondary hypothesis was to investigate whether differences in trunk muscle activity (TrA/IO, EO, sLM and LT) existed between MCI subgroups (AEP and FP) and healthy controls during a series of functional tasks. Additional analyses of the reliability of repeated measures for both spinal kinematics and trunk muscle activity were also conducted. Due to the substantial number of variables evaluated in this study the discussion will follow the same order as the results: subject demographics, spinal kinematics, followed by sEMG.

8.1 Subject Demographics

Subjects who participated in this study were matched for age, BMI and physical activity (IPAQ–SF) between groups however significant differences were observed with regard to gender. Although no significant difference in low back pain prevalence with regard to gender have been reported in recent UK government statistics (126,000 males vs. 10,3000 females in 2013/14) (Health and Safety Executive 2014) in this study the FP group included a greater proportion of male subjects (77.8%) and the AEP group conversely included a greater number of female subjects (82.6%); in contrast the 'matched' healthy control group displayed a more equal gender split. The exploration of gender as a covariate for the kinematic (Table 36) and sEMG data reveals that there may be some influence of gender between groups, with fewer significant results observed, as discussed in section 8.3.4.7. Females have been consistently shown throughout the literature to demonstrate greater lordotic curves in the lumbar region compared with males (Amonoo-Kuofi 1992; Nourbakhsh et al. 2001; Youdas et al. 1996). These proportional gender differences are similar to previous MCI sub-grouped cohorts investigating AEP and FP subgroups. Astfalck et al. (2010b) evaluated an AEP cohort comprising 71.4% females and a FP cohort comprising 78.6% male subjects. Similarly, Dankaerts et al. (2006c) evaluated a disproportionately female AEP cohort (61.5%) with the FP group observed to be primarily male (80%). This within-group gender inequality is a major factor for consideration for all research into the MDCS. Consistently, the kinematic results of the current study show there to be a trend towards the healthy control group consistently adopting postures which lie in a range between the extremes of the FP and AEP postures (in most spinal regions), which may reflect disproportionate gender representation in each of the groups rather than subclassification alone. This then proposes an interesting hypothesis that females and males may need to be sub-grouped differentially as part of a subclassification strategy. Norton et al. (2004) identified that females tend to exhibit an increased lumbar lordosis compared to males ($p<0.01$) to suggest that gender may influence directional LBP subclassification. This work is further supported by Dunk and Callaghan (2005) have previously identified that males sit in significantly more flexion with regard to average lumbar and trunk angle compared to females ($p=0.047$, $p=0.0026$ respectively) in a small ($n=16$) healthy student cohort. Endo et al. (2012) similarly found that females adopt sitting postures with increased sagittal lumbar lordotic angles compared to males in a healthy cohort ($n=50$). However, Ensink et al. (1996) found no correlation between gender, age or body mass of CLBP subjects with regard to lumbar spine ROM, however ROM may not necessarily reflect posture so limited inferences with the current study can be drawn.

The extreme postural differences observed between sub-groups may be interesting phenomena for further exploration with regard to gender. These gender differences appear to be consistently observed

clinically and within research studies (Astfalck et al. 2010b; Dankaerts et al. 2006c), thus gender may be an influencing factor in the adoption of direction specific control impairments and maladaptive behaviours. Future research, or further analysis of the current results, evaluating male and female subjects separately may further enhance our understanding of this phenomena and potential implications for targeted management. This could consider separate analyses for the FP group with a male dominant gender matched healthy control group, and conversely the AEP group analysed against a proportionally female dominant healthy control group.

Although the groups were not matched with regard to gender, considerable efforts were made to match participants for age, BMI and physical activity participation. In this study significant differences were observed with regard to height (AEP vs. FP, FP vs. healthy control) and mass (AEP vs. FP), which is most probably attributable to the difference observed in gender bias, however BMI did not significantly differ between groups. Previous studies have shown a significant, positive correlation between BMI and lower lumbar and upper lumbar spinal angle ($r=0.238$, $p=0.002$; $r=0.203$, $p=0.008$ respectively) (Mitchell et al. 2008). To address such an issue other studies have excluded individuals with higher BMI scores, for example Astfalck et al. (2010b) excluded all individuals with a BMI score greater than or equal to 28 to evaluate trunk muscle activity in an adolescent NSCLBP population. All subjects were included in the current study regardless of BMI and demonstrated average BMI values within healthy limits (20-25) in each group. However some subjects displayed BMI values greater than 25, which are considered ‘overweight’ or ‘obese’. Despite the potential limitations with abdominal sEMG recording and subcutaneous fat over bony processes with retro-reflective marker placement (Section 2.6), subjects with increased BMI were included in the study as these individuals form a significant proportion of the wider general population.

The majority of individuals in both the FP and AEP group reported pain located centrally around the lumbar spine (AEP 56.4; FP 70.4%). Relatively few NSCLBP individuals reported unilateral symptoms especially on the left side (2 AEP; 3 FP) with a similar profile noted between the FP and AEP groups. Therefore site of reported pain probably should not be a confounding variable when evaluating between group differences.

8.2 Patient Reported Measures

No significant between group differences (AEP vs. FP) were observed between the mean questionnaire results for the ODQ, STarT Back, VAS or TSK with both the AEP and FP groups reporting similar levels of disability, risk of poor prognosis, pain intensity and fear of movement to indicate that the NSCLBP sub-groups were appropriately matched for these variables.

Evaluation of the categorised scores for the STarT Back tool results showed that approximately half of all participants in each group (50-56.5%) were classified as 'low' risk (of poor prognosis); the current proposed treatment plan for whom would be physiotherapy advice, reassurance and education (Hill et al. 2011). This is interesting to consider as the following section will demonstrate specific biomechanical differences within these patient subgroups despite little difference with regard to VAS, TSK and ODQ scores. It could be inferred that these 'low risk' subjects may be able to actively 'cope' better than the subjects who score higher on the STarT Back. These individuals at higher risk of poor prognosis may therefore be a key target group requiring specific functional re-education of the maladaptive disorder to elicit long-term change. However, to date no research has demonstrated long term changes in these patient populations following subclassified intervention.

Overall DRAM scores were identified to be significantly different between the AEP and FP groups ($p=0.027$) with the AEP group demonstrated to be significantly more at risk of distress despite no significant differences observed between groups for the MSPQ or MZDI. These findings reflect the proposal that AEP subjects may be more predisposed to hyperactivity of the trunk musculature (Dankaerts et al. 2006a; O'Sullivan 2005; O'Sullivan 2004) and thus may express more hypervigilant traits compared to the FP group to be more distressed and aware of their pain. However this finding was not reflected in pain intensity, disability or fear of movement score, thus may be purely attributable to the small cohort used. The influence of gender may also be a factor for consideration. Women have been shown to report higher depressive scores than males with relation to physical symptoms which may explain the increased AEP DRAM scores observed in the current study (Kroenke and Spitzer 1998).

No significant differences between groups (AEP, FP, healthy control) were observed with regard to physical activity (IPAQ-SF), although, unexpectedly, the healthy control group reported the lowest mean physical activity scores across the 3 groups. Over-reporting of activity levels using the IPAQ has been previously reported in the literature (Lee et al. 2011; Rzewnicki et al. 2003) and may be a potential hypothesis for this observation. It has been widely reported that chronic pain patients have difficulty estimating their own activity levels (Fordyce et al. 1984; Kremer et al. 1981), although other

studies have found objectively assessed physical activity levels not to be associated with pain intensity or level of depression (Huijnen et al. 2010). Huijnen et al. (2010) observed a moderate correlation between subjective reporting and objective measures (accelerometer) of physical activity ($p<0.01$) in CLBP patients (n=66, mean RMDQ scores: 11.8), however in patients with higher levels of depression individuals were identified to subjectively report activity levels lower than those observed objectively. Further analysis of the results from the current study could include evaluation of correlation between DRAM scores and IPAQ reporting to identify if this phenomena is an attribute of this patient group.

No significant differences in mean TSK scores were observed between the AEP and FP groups (AEP 37.5; FP 37.6). The cut-off value for TSK has been proposed to be 37 (Vlaeyen et al. 1995) for distinguishing between 'high' and 'low' fear of movement scores. Despite this indifference, it would be of interest to explore TSK and VAS scores in the AEP and FP individuals who operate beyond the spinal range demonstrated by the healthy control group. Consistently throughout all postural and functional tasks, the upper lumbar and lower thoracic spinal regions in the healthy control group operated in a range between that of the AEP and FP groups with the standard deviations never reaching the extremes of range demonstrated by the AEP and FP groups. It would be of interest to understand more comprehensively the psychosocial profile of these subjects who adopt excessive spinal postures during the functional tasks beyond those of the healthy control group. For example to determine through evaluation of the TSK whether individuals moving primarily at the extremes of range report greater fear of movement, or pain compared to NSCLBP individuals who adopt postures similar to those of the healthy control group.

Pain intensity, recorded using a series of VAS scales (Appendix VI), showed the mean VAS scores for the groups to be 4.5 (AEP) and 4.6 (FP) with a range of 1.0 to 7.5 for average VAS score. These scores can be considered similar to those of Fersum et al's (2013) study, who when evaluating the MDCS, recruited NSCLBP subjects who reported a pain intensity score (NRS) of 2/10 or more in the previous 14 days prior to testing. Although 2 subjects in the current study reported an average pain score below 2/10, this was an average of 4 scores (Appendix VI). Both these individuals reported a pain score 'at worst' >2 thus this population can be considered comparable with Fersum's study with regard to pain. However participants were not included in Fersum et al's (2013) study if they had a disability score, measured using the ODQ, of less than 14%. In the current study 6 FP and 5 AEP individuals were identified to report disability score totalling less than 14%, however these individuals met the eligibility criteria and displayed maladaptive MCI therefore were included to give a comprehensive overview of these patient cohorts. Fersum et al. (2013) also excluded participants who had had a continuous absence from work due to LBP for more than 4 months as the authors felt that specific intervention to facilitate return to work (i.e. focus on work specific tasks) would be

required. In this study 1 participant (AEP) reported being unable to work due to LBP and was receiving Employment and Support Allowance, however as this study was purely observational and not intervention related it was felt that this would not be a significant confounding factor. Similarly to Fersum et al. (2013) all other participants were either currently employed, studying or retired with no current absence from work reported. It could be theoretically expected that disability scores would therefore be lower, as the majority NSCLBP individuals reported only either minimal or moderate disability levels overall (ODQ). As will be discussed later, despite these lower disability scores, significant biomechanical differences were still observed.

8.3 Spinal Kinematics

8.3.1 Kinematics - Within-Day Reliability

Evaluation of the reliability of repeated trials with regard to regional sagittal spinal angles revealed good to excellent test re-test reliability across all functional tasks (ICC 0.449 to 0.924; SEM 2.9° to 10.5°). These results are similar to those obtained by Hidalgo et al. (2012) where a similar marker set was found to exhibit good to excellent reliability (repeated measures) of active trunk ROM in sitting in both healthy individuals and a NSCLBP group (ICC 0.70-0.96, SEM (%) 19.4-3.3) in the upper thoracic (C7–T7), lower thoracic (T7–T12), upper lumbar (T12–L3), lower lumbar (L3–S2) and total lumbar (T12–S2) spinal regions, similar to those regions defined in the current study. Hidalgo et al's (2012) marker set used fewer spinal markers from which to obtain the regional data (i.e. each spinal region was calculated as a gross angle between 2 markers alone). The marker set utilized in this current study incorporated a greater number of thoracic and lumbar markers thus theoretically should provide a more representative indication of spinal movement including consideration of segmental differences. The current study reports reliability during functional movements, which are likely to use less overall range, thus the current results appear to demonstrate a highly reliable methodological approach for analysis of regional sagittal spinal profile during functional tasks.

A difference between Hidalgo et al's (2012) study and the current study however was the number of repetitions, Hidalgo et al. (2012) recorded 10 repetitions compared to 3 for the current study. For test re-test reliability studies, Hopkins (2000) states that for repeated measures of reliability at least 3 trials should be undertaken, consistent with this protocol. Ideally a greater number of trials would have been completed to ensure a more robust evaluation of test re-test reliability, however due to the potential for symptom reproduction during repeated tasks, a greater number of repetitions was not chosen. It is accepted that repeating this study with greater subject numbers and trial repetitions would be advantageous to further support or negate these findings.

Gracovetsky et al. (1995) similarly identified that variation in movement in the lumbar spine was small during flexion and extension movements in healthy individuals, despite the potentially large degrees of freedom available to perform such a movement. The findings from the current study suggest that both healthy control subjects and NSCLBP subjects move in consistent movement patterns, not only in the lumbar regions but throughout the spine during functional activities. These results also appear to be consistent with previous results obtained for lumbar spinal angles derived using electro-magnetic devices (e.g. 3Space Fastrak®). Astfalck et al. (2010b) reported the ICC values for sacral, lower lumbar, upper lumbar and total lumbar angles, albeit in an adolescent population in usual sitting and slumped sitting (3 repetitions), ranged from ICC 0.882 to 0.969 with SEM values ranging from 1.0° to 1.7°, demonstrating greater accuracy compared to the current study. However it is important to note that these values were obtained purely from usual sitting and usual sitting postures. As well as a difference in methodological approach and sample, evaluation of functional tasks is dynamic enabling subjects to move through multiple degrees of freedom to achieve any single aim, thus it is reasonable to anticipate greater variability in results between consecutive trials. Despite this, within-day variability values for each task in the current study were identified to be good to excellent thus supporting this methodological approach and ascertaining that subjects move consistently throughout the trials

Another important consideration for future investigation with regard to within-day reliability using spinal marker sets is the role of the pelvis in functional movement variability. The angle of pelvis inclination could provide valuable information regarding whether the pelvis position remains consistent between trials, despite consistency in the regional sagittal spinal angles. Previous studies have shown that high ODQ scores are correlated with pelvis inclination in women with CLBP, and lumbar extension ROM related to pelvic inclination in men with CLBP (Youdas et al. 2000). Similarly, alteration of seated pelvic inclination for specific subgroups (AEP, FP) have been shown to influence low back discomfort levels (Curran et al. 2014; O'Keeffe et al. 2013). Pelvis position plays a key role in the motor control of the thoracic and lumbar spine due to the numerous ligamentous and muscular attachments in the lumbopelvic region. Therefore the pelvis is likely to be a discriminatory factor between healthy and NSCLBP sub-groups. Sheeran et al. (2013) in a pilot study demonstrated that classification guided postural intervention which included pelvis inclination re-education produced both a statistical and clinical short term reduction in disability in NSCLBP subgroups (AEP and FP), therefore pelvis position is a key consideration for future research and re-evaluation of the data set generated by the current study.

8.3.2 Kinematics – Postures

8.3.2.1 Usual Standing

During usual standing the current study identified a significant difference ($p<0.05$) between the AEP and FP group, and the FP and healthy control group in the upper lumbar spinal region only. In both instances the FP group displayed significantly greater flexion in the upper lumbar spine compared to both the AEP and healthy control groups. This finding is of interest as no significant differences were observed in the lower lumbar region or the total lumbar region. This may be due in part to an opposing trend in the lower lumbar spine where, in contrast to the upper lumbar region, the FP group appears to adopt a posture in slightly more extension to the AEP and healthy control groups. This finding is of interest as it further highlights the need for the spine to be considered in sub-divided regions, due to a potential 'wash out' effect of combining the upper and lower lumbar spine regions, as explored by Mitchell et al. (2008). This general trend was similarly apparent in the upper lumbar region between the AEP and FP groups, however this narrowly missed significance ($p=0.058$). No differences in any other spinal regions were identified.

Previous understanding has been that measurement of lumbar spinal posture using skin-surface techniques is not able to discriminate between LBP and healthy subjects (Laird et al. 2014). This is reflected in the current study by the lack of a significant difference when the lumbar spine was considered as a total entity. However, interestingly this current work highlights that significant differences in other spinal regions between NSCLBP subgroups can be established using skin-surface techniques. The lack of any significant difference in the total lumbar region may be due to the omission of sub-divided spinal regions in previous literature and the lack of clear classification strategies to identify subgroups of individuals displaying distinct postural and movement behaviours. All significant differences in spinal angle during standing were observed in the upper lumbar region only. It has been previously identified (using radiographic techniques) that although two thirds of the total lumbar lordosis observed across all individuals (both healthy and CLBP), is displayed at the L4-5 and L5-S1 levels, subjects with LBP adopt less lordotic postures in the lower lumbar region and greater lordosis in the upper lumbar spine (Jackson and McManus 1994). This conflicts with the current study findings where no significant differences were noted between groups in this lower lumbar spinal region.

Whilst the study by Jackson and McManus (1994) did not incorporate any form of classification approach to the LBP individuals the results suggest that habitual postural behaviour may be influenced by the presence of pain during standing. This may provide some explanation as to why the current study results showed no differences in the lower lumbar spinal region between groups, especially with regard to the NSCLBP subgroups. It may be that there is a tendency for patients

experiencing extension related pain to over-arch the thoraco-lumbar spine, a trend observed throughout the functional tasks. One possible explanation for this may be the reduction in spinal acuity (i.e. joint position sense) in achieving neutral spinal posture (Allison and Fukushima 2003; Astfalck et al. 2013; Brumagne et al. 1999; O'Sullivan et al. 2013b; Sheeran et al. 2012). If, as a result of pain the patient becomes inhibited to movement through a fear avoidance response, they may experience diminished ability to actively control, or even move, the affected lower lumbar spinal segment through fear of re-injury. Differences in lumbar spine repositioning error and proprioception between back pain and healthy individuals in standing have been previously observed (Gill and Callaghan 1998; Sheeran et al. 2012). Sheeran et al. (2012) observed the AEP group to significantly overestimate a neutral lumbar spine target angle ($p<0.016$) compared to the healthy control group. In the current study no differences between AEP and the healthy control group were identified in standing. Although the outcomes of interest differed in the Sheeran et al. (2012) study compared to the current study (spinal repositioning error as opposed to sagittal spinal angle), direction specific differences, and potential differences in proprioceptive awareness of the spine appear to be present between groups. The lack of a difference between the AEP and healthy control groups in the present study may be due to the size of the cohort under investigation. However, visual inspection of the graphs in the current study appear to show the AEP and healthy control groups to adopt similar mean angles in each spinal region to suggest that the AEP and healthy control groups display similar postural standing characteristics. Further, interpretation of these findings becomes less clear when considering the proposed MDCS. O'Sullivan (2005) proposes that, anecdotally, AEP subjects may be more likely to report pain during standing compared to the FP group, although this may be duration dependent. However the results observed in the current study suggest that, at the time of testing the AEP group demonstrated marginally lower mean pain scores compared to the FP group in usual standing (NRS score 1.4 compared to 1.8) (Table 18). It may be that standing for a few seconds is insufficient to provoke pain in the AEP group and that further testing with individuals standing for prolonged periods is warranted. Additionally, if the AEP group adopt standing postures more aligned with healthy control subjects it may be that other motor control factors, such as neuromuscular control or muscle activity may be a greater influence on pain in this NSCLBP subgroup.

8.3.2.2 Usual Sitting

Sitting over prolonged periods of time is widely acknowledged to be a key aggravating factor for LBP (Andersson 1981; Kelsey and White 1980). Extreme lumbar curvature with anterior pelvic tilt has been shown to cause increased discomfort in healthy individuals (Vergara and Page 2002). Sitting postures where the lumbar spine is positioned in slight lumbar lordosis (approximately 30% from end-range extension), with associated slight anterior pelvic tilt and thoracic relaxation has been proposed

to be optimal for LBP patients, as opposed to adopting end-range postures (O'Sullivan et al. 2010; Vergara and Page 2002).

The current study identified significant differences in sitting between the AEP and FP groups in the total lumbar, upper lumbar and lower thoracic spinal regions ($p<0.05$), with the FP group displaying significantly greater flexion in these spinal regions compared to the AEP group. Significant differences were also observed between the FP group and healthy control group in the upper lumbar and lower thoracic spinal regions. No significant differences were identified in any other spinal region or between the AEP and healthy control groups. Interestingly, significant differences were still observed between the AEP and FP groups in the lower thoracic and upper lumbar spine when gender was considered as a covariate in the analysis, signifying that postural differences between subgroups may be most noticeable in usual sitting positions.

The incidence of increased extension in these spinal regions in the AEP group support previous findings (Bennett et al. 1989; Vergara and Page 2002) where lordotic lumbar spinal postures have previously been shown to be associated with increased discomfort. However, O'Sullivan (2005) proposes that the FP group are anecdotally more likely to report pain during sitting compared to the AEP group and adopt postures at the extreme range of flexion. This is observed, to an extent in the verbally reported NRS pain scores (Table 18) where the FP group report marginally higher mean pain scores during usual sitting in the current study. However both groups report very mild pain on average thus it is difficult to extrapolate these observations to the wider NSCLBP population.

These findings in part both agree with and dispute aspects of Dankaerts et al. (2006c) research. Dankaerts et al. (2006c) observed differences in usual sitting posture in the upper lumbar region between the AEP group and the FP group ($p<0.001$). In contrast to the current results, significant differences were also observed between the AEP group and healthy group ($p<0.001$) with no between group differences observed between the FP and healthy control groups. Additionally, in conflict with the current results, significant differences between all 3 groups in the lower lumbar region in usual sitting were noted ($p<0.001$). These findings may be due to differences in methodological approach, as the study recorded spinal angle using an electromagnetic 3Space Fastrak® device. Additionally, differences in results obtained may be due to the small sample size utilized in Dankaerts et al. (2006c) study where a sample of 20 FP and 13 AEP subjects was investigated. Additionally the NSCLBP population tested in the current study were older (on average) (42.4 years compared to 37.8 years) and demonstrated lower average BMI scores (22.1kg/m^2 compared to 24.4 kg/m^2) compared to Dankaerts (2006c) study. In all instances in Dankaerts et al. (2006c) study the AEP group adopted more extended lumbar-pelvic postures, FP more flexed lumbar-pelvic posture, with the healthy group

consistently adopting postures in a range between the two NSCLBP subgroups, which is reflective of the current results and further supports the MDCS and presence of distinct MCI subgroups.

In further support of Dankaerts et al. (2006c), but in contrast to the current results, Van Hoof et al. (2012) observed a significant increase in flexion in the lower lumbar spinal region in cyclists with FP MCI whilst cycling ($p=0.018$) compared to healthy cyclists. Similarly, these differing results will be influenced by the difference in activity, sitting whilst cycling is a different posture to usual habitual sitting and may thus predispose the lower lumbar spinal region to a more excessive flexed posture. Difference in methodological approach using a wireless posture monitoring system could also be regarded as a factor for consideration, however the posture adopted is substantially different from the posture observed in the current study thus this factor may have less bearing on the overall results observed.

However the current study results are reflective of those observed in an adolescent population. Astfalck et al. (2010b) identified significant differences in usual sitting in the upper lumbar and total lumbar regions but not in the lower lumbar spinal region. With regard to total lumbar spinal angle the AEP group adopted significantly more lordotic postures compared to both the healthy control and FP groups ($p=0.002$), whereas in the current study only significant differences between the AEP and FP groups were identified ($p<0.05$). In the upper lumbar region significant differences were observed between all 3 groups (FP, AEP and healthy control), whereas in this study differences were only observed between the AEP and FP, and FP and healthy control groups This may be due to the adolescent population used and a difference in methodological approach (3Space Fastrak®) using an electromagnetic device. It could be hypothesized that age may be a factor for consideration, however in the current study the cohort was older (mean 41.1 years) than both Van Hoof et al's (2012), and Dankaerts et al's (2006c) cohorts (mean 28.4 years and 36.0 years respectively), in comparison to Astfalck et al's (2010b) adolescent cohort (mean 15.6 years). Gender representation throughout the groups however was comparable between Dankaerts et al's (2006c), Astfalck et al's (2010b) and the current study; however only males FP subjects were evaluated by Van Hoof et al. (2012).

The between group differences observed in the lower thoracic spine are novel findings in this current study. Astfalck et al. (2010a) found no significant differences in trunk angle between groups, although (following adjustment for gender differences) a trend for a reduction in overall trunk angle in the AEP group when compared with the FP group was observed. This suggests the AEP group may adopt a less kyphotic trunk angle compared to the FP group, however trunk angle was evaluated using sagittal photographs with markers placed at C7 and T12, which may not be sensitive to detecting the regional differences. The current findings support this observed trend, however evaluation of total spinal angle

cannot identify regional differences in posture and thus is insufficiently sensitive to identify differences between classified subgroups.

It appears that the findings of the current study further support the proposed biomechanical differences in regional spinal kinematics during static postures as identified previously, however the specific lumbar spinal regions demonstrating this difference appear to vary throughout the literature. A difference in lower thoracic spinal posture in sitting is a novel finding which suggests that the thoracic spine is an important area for clinical assessment in determining between group differences using the MDCS.

8.3.3 Kinematics - Range of Movement

8.3.3.1 Flexion

During full flexion from usual standing significant differences were observed between the AEP group and the FP group in the total lumbar spine region ($p<0.05$) with the AEP group achieving significantly less overall spinal flexion. No significant differences in this region were observed between the FP group and the healthy control group or between the AEP group and the healthy control group. Although the AEP group appeared to achieve less overall range of spinal flexion through this movement compared to the healthy control group (Figure 23) this observation was shown to be non-significant ($p=0.069$).

Following subdivision of the spinal regions this significant difference was only replicated in the upper lumbar spinal region ($p<0.01$) between the AEP group and the FP group, indicating this to be the region difference primarily contributing to the significant difference observed in the total lumbar spine. The results may indicate an altered movement strategy in the AEP group when moving into full flexion it could be theorised that this may be due to pain inhibition and fear avoidance. It is of note that no differences in any other spinal regions, including the thoracic spine regions were observed during flexion, indicating that the upper lumbar spine is a key region for differentiation between groups during full flexion.

In contrast with the current study, Esola et al. (1996) reported spinal ROM to be no different between healthy and LBP groups. This may due to the omission of a subclassification strategy as it is clear from the current results that the AEP and FP groups adopt postures nearer end ROM in opposing directions, thus by considering these subgroups collectively the ‘pooled NSCLBP’ group and the healthy control group may present similarly. Although spinal ROM demonstrated no significant

differences between groups, the pattern of movement of the lumbar spine and hips into full forward bending was different with the LBP group utilizing greater lumbar ROM through the initial stages of the movement (Esola et al. 1996). The analysis employed for the current study evaluated the maximum and minimum values from which the midpoints were derived. Further analysis of the data to explore differences within the task at differing time points would be of interest to establish whether the manner in which the tasks were performed varied between groups.

In contrast to Esola et al. (1996) spinal mobility has been shown to be reduced in adults with either a previous history of LBP or currently symptomatic LBP (Burton et al. 1989). Burton et al. (1989) recorded maximum lumbar spine sagittal mobility using flexicurve measurements and observed a reduction in spinal mobility in adults with a history of, or current, LBP. The difference in study results may be due in part to the wider age range of the subjects in Burton et al's (1989) study (10-84 years) compared to 23-46 years (Esola et al. 1996) and 18-64 years in the present study. The sample size for Burton et al's (1989) was also significantly larger (n=958) than both the current study (n=79) and Esola et al. (1996) (n=41). In the current study, as an integral aspect of the MDCS for motor control impairment, NSCLBP subjects were only included into the study if they presented with full ROM. Burton et al. (1989) did not employ a subclassification strategy beyond 'current' or 'history of' CLBP thus considering NSCLBP as a heterogeneous group of potentially differing presentations, thus this may be a contributory factor to the differing results obtained. Additionally it may be that the use of a flexicurve device, opposed to 3D optoelectronic motion analysis, may account for between study variations.

Similarly to the current study, Burton et al. (1989) also found the upper lumbar region be a key spinal region for observing differences in range of motion between LBP subjects and healthy controls. Burton et al. (1989) found that reduced mobility was more apparent in the upper lumbar spinal region in LBP (current and previous) individuals, when compared with healthy subjects to further support the presence of regional spinal differences. In the current study the AEP group demonstrated an overall greater reluctance to move into full flexion range of motion in this spinal region, however the FP group operated into flexion in a range similar to the healthy control group. This may be hypothesised to be due to fear avoidance strategies in anticipation of perceived pain provocation. The current study results further support these findings albeit only for one subgroup (AEP), however the upper lumbar region does appear to be a key area for further evaluation as a region which is consistently demonstrating differences between NSCLBP subgroups and healthy control subjects.

Limited literature currently exists regarding ROM quantification during full range of spinal flexion and extension in LBP and healthy individuals, thus comparisons with existing literature are difficult to ascertain. It is clear from the current study findings however that subgroups of NSCLBP subjects

adopt regionally specific ROM strategies. These findings are important for understanding how subgroups of NSCLBP individuals may habitually adopt or develop postures, which are direction specific and thus predispose ongoing pain provocation and adverse tissue loading around the spine. However it is still unclear why not all subjects with these postures experience pain. Whether individuals who adopt such postures are more predisposed to pain or whether these postures are adopted as a result of pain remains to be established, although this is difficult to prove as studies evaluating postural development from childhood would be needed. It would also be of interest to evaluate whether the development of such postures are influenced predominantly by other variables such as environmental factors or structural changes in and/ or composition of tissues.

8.3.3.2 Extension

Interestingly, full extension presented results differing substantially to the postures, full flexion and functional tasks. The only significant differences identified between the AEP and FP groups were observed in the upper thoracic spinal region. In this upper thoracic region a reversal of the previously identified trends was observed with the FP group operating into greater extension compared to the AEP group. Interestingly throughout the full extension task, visual inspection of the graphs (Figure 24) shows the AEP group do not significantly differ, with regard to midpoint spinal angle, compared to the healthy control group throughout this task. These findings, when considered in conjunction with those of the FP group during the flexion task demonstrate that these two subgroups appear to operate in a similar ROM to healthy controls in the primary direction of the disorder as proposed by the MDCS (i.e. FP similar to healthy controls during flexion in all spinal regions, AEP similar to healthy controls during extension in all spinal regions). This therefore questions the rationale of the MDCS (O'Sullivan 2005).

The magnitude of an individuals thoracic kyphosis has been proposed to influence ROM in the thoracic spine in healthy individuals (Edmondston et al. 2012). During the previously described standing postures overall thoracic kyphosis was identified to exhibit no significant between group differences however the FP group were identified to adopt significantly more flexed, or kyphotic, postures in the lower lumbar spine compared to the AEP group however during extension no between group differences were noted in this spinal region. Edmondston et al. (2012) measured ROM and thoracic kyphosis using radiographical analysis in a healthy cohort alone. Radiographical analysis would provide a more sensitive measure of intervertebral movement, whereas the current study was restricted to analysis of surface markers. The novel marker set developed used spinal markers on every alternate spinous process to most accurately evaluate total regional spinal movement. However, during a task such as extension, surface marker proximity becomes more narrowed and thus the

likelihood for ‘cross-over’ of marker positions or visual loss of markers in subjects with hypermobility into extension as noted by Whittle and Levine (1997). It may be that increased marker loss and subsequent increased approximation of marker positioning during this task may have affected the accuracy of the results obtained.

It appears that extension may not be a sensitive task for defining between group differences. The majority of tasks of daily living have an emphasis on flexion e.g. picking up items from the floor, ironing, brushing teeth etc. Few functional movements utilise the extreme ranges of extension and thus, as an unfamiliar movement, it may be that individuals do not utilize full available spinal ROM, leading to the paucity of significant differences identified. Additionally the unexpected increase in upper thoracic extension in the FP group may be reflective of maladaptive spinal behaviour caudally. If FP individuals exhibit a reduction in SPS into extension in the thoracic and lumbar regions, as observed by Sheeran et al. (2012), it may be that alternative strategies are employed to achieve extension activities. For example, if the FP group tend to maintain greater flexion in the area between T6 and L3, this group may employ a movement strategy which relies on increased upper thoracic extension or excessive cervical extension in order to achieve an ‘extension’ movement.
Verbally reported pain scores during extension ROM were unexpectedly greater for the FP group compared to AEP, which may reflect why few significant differences between groups were observed. It may be that the AEP population tested did not have baseline pain levels sufficient to observe significant differences in pain through this activity. Alternatively, these results indicate that the MDCS proposal that AEP subjects report pain on activities with an extension bias is not warranted and instead these individuals are able to adopt movement patterns more similar to pain-free individuals. This is reflected throughout the results where no significant differences between the AEP and healthy control groups are observed.

8.3.4 Kinematics - Tasks

8.3.4.1 Hierarchy of Tasks

A hierarchy of tasks with regard to ROM was included in the thesis to explore the relationship between the tasks with regard to ROM (Figures 25 and 26). The MDCS proposes that the AEP and FP MCI subgroups are direction specific thus the degree to which each task is biased towards either flexion or extension is of interest when interpreting results. As expected the reach task operated in the greatest degree of overall lumbar spine extension and, as anticipated, the pick up pen (bend) and pick up pen (return) tasks demonstrated the greatest overall emphasis towards flexion (-5.8° and -5.6° respectively). The hierarchy is generally unsurprising overall with the tasks with the bias towards

standing; step up (-31.5°), step down (-29.3°) and box replace (-20.2°) demonstrate the next greatest degrees of total lumbar extension after the reach task. The sit-to-stand task, as a task incorporating 'sitting' postures demonstrated the greatest proportion of overall flexion bias (-16.8°) after the pick up pen tasks. Bible et al. (2010) has reported the normal ROM of functional tasks in healthy individuals, expressed as overall percentage of total active ROM of the lumbar spine during flexion and extension. Concurring with the current study findings, bending was shown to require the greatest overall ROM (59%), followed by sit-to-stand (39%), stand-to-sit (37%), step up (13%) then step down (11%), displaying a replicable hierarchy to the results shown here, albeit with regard to % of range as opposed to midpoint spinal angle. Although it should be taken into consideration that these are the results of healthy individuals the current study findings suggest that demographics bear similarities (mean age 40.2 years, 60 subjects (30 male, 30 female)). And importantly, this hierarchy was maintained when the subgroups and healthy control groups were considered individually (Figure 26) thus the current findings concur with Bible et al. (2010) to suggest that NSCLBP utilise similar ROM during functional tasks to healthy subjects.

Interestingly, the NSCLBP subgroups follow the same pattern as the healthy control group albeit with different offsets as they consistently shift their angles. As can be observed in Figure 26, generally the AEP group demonstrates overall more extended total lumbar postures compared to the FP group. The healthy control group, for each functional task, tend to adopt midpoint total lumbar angles in a range between the FP and AEP values. The inclusion criteria for all NSCLBP subjects' states that all participants must demonstrate full spinal ROM clinically, however it is an interesting observation that midpoint total lumbar angle differs slightly between all groups in each task. The hierarchy of tasks provides a framework to further explore the demands made upon the spine across the 3 groups.

8.3.4.2 Reaching

During the reaching task the FP group operated in significantly greater flexion compared to the AEP group ($p<0.05$) in the upper lumbar spine, and in relation to the healthy control group, however this was a non-significant observation ($p=0.058$). No other significant differences were observed in any other spinal region. The hierarchy of the tasks (Figure 25) demonstrated reaching to be the task comprising the most extended lumbar posture, although no differences between any groups in upper thoracic spinal posture (as observed during maximal extension) were noted. In accordance with the extension task findings, the AEP and healthy control groups appear to adopt similar strategies for movement throughout the spinal regions with the FP subjects appearing to be unwilling to operate into full extension ROM in the lower thoracic spine. Silfies et al (2009a) found multiple lumbar movement strategies to be present within subjects with mechanical LBP (MLBP) during a bilateral forward

reaching task, hence highlighting that sub-groups may be concealed within this larger heterogeneous MLBP group. The current study findings conversely found little overall difference during a reaching task ($p \geq 0.103$ except in the upper lumbar region ($p=0.011$)), however the nature of the reaching tasks performed varied tremendously between Silfies et al (2009a) and the current study: bilateral forward reach compared to unilateral upward reach respectively.

Silfies et al (2009a) identified that the MLBP group adopted a pelvis-dominated movement strategy to achieve the forward reach. Conversely, the healthy control group was found to adopt an alternative 'lumbar-synchronised-lumbar' motion (Section 2.5.1.3) to complete the forward reaching task. Since the task employed in the current study did not place such biomechanical demands on the individual the task may not have utilised a ROM extreme enough to warrant significant differences or differences in movement strategies.

Reaching was the only functional task where no significant differences were observed on the lower thoracic spine, although visual differences in midpoints and range are observed. This may be due to the task, as in order to achieve the aim of placing an object onto the shelf subjects may not have needed to utilise excessive end range spinal postures. The task may have instead placed the greatest demand on right upper limb movement in order to achieve the aim.

8.3.4.3 Step Up and Down

In both the step up and step down tasks significant differences were observed between the AEP and FP group; and FP and healthy control groups in the upper lumbar spinal regions with the FP group consistently demonstrating greater mean flexion compared with the other groups ($p<0.05$). This significant difference between the AEP and FP groups was further reflected in the total lumbar spine angle but only during the step down task. Consistently during both tasks the AEP group demonstrated significantly greater mean extension angles in the lower thoracic region when compared with the FP group ($p<0.05$). No significant differences were observed between the AEP and healthy group in any spinal region, which is surprising given differences previously observed in sitting postures between the AEP and healthy control groups in previous studies (Astfalck et al. 2010b; Dankaerts et al. 2006c). This observation is noted throughout all functional tasks, which suggests that AEP and healthy control subjects may adopt postures and spinal movement patterns more aligned to those of healthy individuals, more so than the FP group.

Surprisingly, little work has been conducted to date evaluating spinal motion and posture during stair ascent and descent, with the majority of the literature only exploring ankle, hip and knee biomechanics (Costigan et al. 2002; Nadeau et al. 2003; Protopapadaki et al. 2007). These tasks were

deemed to be important to include in the study as they are clinically important functional activities needed to be performed by the majority of individuals. Work by Bible et al. (2010) identified that greater lumbar flexion was required to ascend stairs compared to descend (11 vs. 8 degrees, $p<0.0001$). This finding is reflected in the current study with slightly greater mean (midpoint) values for total lumbar flexion during step up compared to step down across all groups (AEP -33.4° vs. -36.3°, FP-26.4° vs. -27.3°, healthy control -28.7° vs. -31.8° respectively). The difference in mean (midpoint) spinal angle between the FP and AEP groups is greater during the step down task (compared to step up), with the AEP group observed to operate in slightly greater overall extension in the upper lumbar region. This further emphasises unwillingness of these AEP individuals to utilise lumbar flexion range during this, potentially less flexed activity. However, since no significant differences were observed between the AEP group and healthy control group it could be hypothesised that this is due to these groups operating more similarly.

It has been previously reported that stair ascent and descent require equivalent amounts of ROM in all planes of movement (Bible et al. 2010), hence it may be of interest in future to evaluate if between group differences occur in the transverse and frontal plane. Using the spinal marker set developed for the study, changes in all 3 planes of movement can be analysed at a future date.

8.3.4.4 Box (Lift and rotate tasks)

Consistent with previous findings in the step tasks, the FP group were found to significantly differ from both the AEP and healthy control groups in both the upper lumbar and lower thoracic spinal regions during the replace the box task. However the difference between FP and healthy control groups in the lower thoracic region did not quite reach significance ($p=0.068$). Similarly, significant differences were observed in the lifting aspect of the box task between the AEP group and the FP group in the lower thoracic and upper lumbar spinal regions however no significant differences were observed between the FP and healthy or AEP and healthy control groups in any spinal region during this task.

Tasks which require flexion and rotation are often reported by NSCLBP patients as a trigger for pain onset and have been believed to be of significant diagnostic value in understanding LBP (Allison and Fukushima 2003). These findings suggest that the FP subjects continually adopt flexed postures during this activity in the thoraco-lumbar region. This may be hypothesised to be due to the avoidance of spinal extension due to perceived fear of pain onset, which may in turn predispose individuals to injury through compromised flexed, rotated and loaded spinal postures. It may also be argued to be purely habitual. Clinically, this is an aspect for consideration as it could be that some patients are

unaware of these pain provocative spinal postures and movements and will therefore be unable to alter them unless made consciously aware by the clinician. This box lifting rotational task is also highly asymmetrical which may have an influence of pain especially in instances where pain is not localised to the centre of the lumbar spine. This is a key consideration for future work, however unilateral differences were observed with regard to EO and sLM muscle activity during these tasks (Table 41).

It could be purported that these observed kinematic differences between the AEP group and FP group may be due to repositioning error and alterations in joint position sense in these NSCLBP individuals. However the non-significant differences observed between the AEP group and healthy control group negate such a hypothesis for the AEP individuals. No differences in accuracy or precision in repositioning error across 10 repeated trials during a flexion-rotation task in healthy individuals has been identified however whether there are differences in repositioning error in LBP populations remains to be ascertained (Allison and Fukushima 2003).

A limitation of the protocol for the box lifting and replace tasks is the strict instructions the participants were subjected to in order to standardise the protocol between individuals. Asking the subjects to adopt a more habitual approach to the task (i.e. self-identified foot placement, no targets for box placement) may have been more representative of usual functional activity within these patient subgroups however the substantial increase in sample size required to undertake this approach was considered unfeasible for this PhD project and thus the standardised approach was used. The height at which the box was lifted is another factor for consideration. Spinal kinematics have been shown to remain unchanged during lifting tasks with weighted objects at differing heights in a healthy cohort (El Ouaaid et al. 2014) further supporting the approach used, however this may differ in NSCLBP populations.

8.3.4.5 Sit-to-Stand-to-Sit

Stand-to-sit and sit-to-stand tasks demonstrated consistently significant differences, similar to those identified during the box and step tasks. During the sit-to-stand-to sit tasks the FP group demonstrated significantly greater overall flexion in the lower thoracic region when compared to both the AEP and healthy control groups. In the upper lumbar regions this pattern was similar although it did not reach significance between the FP and healthy control groups ($p=0.055$ stand-to-sit; $p=0.096$ sit-to-stand). As observed in the other functional tasks, no significant differences were observed between any groups in either the upper thoracic or lower lumbar spinal regions. Interestingly, a general trend ($p<0.1$) was observed between the AEP and healthy control groups in the upper lumbar region during the sit-to-stand-to-sit tasks. Although non-significant a clear visual difference in spinal angle, with the

AEP group adopting significantly greater extension compared to the healthy control group is observed. Visually, this is a trend seen throughout all the functional tasks, where the healthy control group appears to adopt a 'mid-way' range between the extremes of the FP and AEP subgroups, however this rarely reaches significance. It may be that this phenomenon is present throughout all tasks in the upper lumbar and lower thoracic spinal regions and that, despite the power calculation (Appendix VII), the group sizes may have been insufficiently powerful to detect subtle changes in angle during functional tasks.

End range habitual spinal posture may be a defining characteristic for these NSCLBP subgroups. Shum et al. (2005a) observed spine and hip mobility to be significantly compromised at peak lumbar flexion in a sub-acute LBP (>7 days <12 weeks) population compared to healthy control subjects during sit-to-stand, which is reflective of the AEP presentation observed in the current study. However, their male only cohort could be hypothesised to potentially reflect a bias towards individuals with an FP presentation, as proportionally more males than females appear to be classified into FP subgroups in this current study and previous work (Astfalck et al. 2010b; Dankaerts et al. 2006a, c). Further research is needed to establish a more comprehensive appreciation of both healthy and symptomatic spinal posture and movement strategies. Evaluating mobility at the hip (from the existing data set) during this activity would also be an interesting avenue to explore for future work.

Svendsen et al. (2013) identified no significant differences in overall trunk angle between sub-acute LBP populations and healthy control subjects during sit-to-stand as well as during spinal flexion (in standing) and box lifting activities. However, differences in the methodological approach (calculation of total spine angle from PSIS', acromion and L5 markers alone) and omission of a specific subclassification approach limit comparability.

The current findings suggest that differences are apparent when the spine is considered as a series of sub-divided regions, rather than a single entity, and that subclassification of LBP is essential to distinguishing between individuals with NSCLBP and healthy subjects. However it is worthy to note that Svendsen et al. (2013) used a sub-acute LBP population (0-6 months since onset), thus it may be hypothesised that these individuals do not express the same established maladaptive characteristics as those with chronic pain presentations lasting years. In the current study, NSCLBP patients reported pain more than 3 months post-onset with the majority (AEP 91.3%; FP 70.4%) reporting pain beyond 6 months. Additionally, in the current study a substantial proportion of individuals reported pain persisting more than 10 years (AEP 21.7%; FP 14.8%) thus the populations are not comparable. It would be interesting in future work to evaluate how these maladaptive spinal movements of subgroups may alter from acute pain through to chronicity.

Considering the hierarchy of tasks as presented in Figure 25, it could be anticipated that the sit-to-stand-to-sit tasks would demonstrate a greater bias towards the FP group operating in a similar range to the healthy control subjects. However, as seen all the other functional tasks this does not necessarily appear to be the case, with the FP group appearing to deviate more from both the AEP and FP groups. This may be due to the fact that, despite this task being more biased towards 'less extension' the lumbar spine is still in a relative degree of overall extension (or lordosis) thus is not truly a 'flexion dominant' task (i.e. lumbar lordosis > 0 degrees) (Figure 25).

8.3.4.6 Pick Up Pen (Bend and Return)

The pick up pen (bend and return) tasks mirror the findings of the previous tasks. During the bending aspect of the task the FP group displayed significantly greater flexion angles in the upper lumbar and lower thoracic spinal regions compared to both the AEP and healthy control groups ($p \leq 0.044$). These findings were further replicated in the return phase of the task however no significant differences between the FP and healthy control group in the upper lumbar spine were observed.

The pick up pen tasks (bend and return) demonstrated the greatest degree of overall lumbar flexion (Figure 25) compared to the other functional tasks, therefore it could be theorised that the results would demonstrate a difference between the AEP and FP, and FP and healthy control groups as the FP groups were hypothesised to operate into the greatest flexion range during flexion biased tasks. As anticipated, differences were observed between the AEP and FP group, with the AEP group appearing to adopt spinal postures or movement more aligned to those of the healthy control group.

Although the start position, location of pen and the upper limb used to retrieve the pen were standardised the subject could choose a self-selected technique to retrieve the pen. For example squatting or utilising a technique biased towards greater hip and lumbar spine flexion. This introduces further variation with regard to technique therefore it is difficult to interpret spinal movement preference from this data set. Further analysis of the data with sub-analysis for choice of task performance may therefore be of interest.

8.3.4.7 Overview of Functional Tasks

Overall, the AEP group was found to operate in significant extension compared to the FP group during all functional tasks in the upper lumbar and lower thoracic spinal regions ($p<0.05$), with the exception of the lower thoracic spine during the reach up task where no significant differences were observed in these regions. This may be a reflection of the extension-biased nature of the task where ROM in this region appears to be similar across all groups.

According to the hierarchy of tasks (Figure 26), all tasks, with the exception of the pick up pen task (FP group only) operate with the mean (midpoint) lumbar spine angle in lordosis (mean angle < 0 degrees) thus none of the tasks required the subjects to move the lumbar spine into substantial flexion postures. During all tasks all significant differences were noted between the FP group and either the AEP or healthy control groups. In no instances were significant between group differences identified between the AEP and healthy control groups, intimating that the AEP and healthy control groups move in more similar patterns of movement during functional tasks. It could be that these functional tasks did not place sufficient demand on lumbar spine flexion and thus the AEP group were not required to move into the ROM where they would demonstrate fear avoidant strategies. This was demonstrated by the general trend ($p<0.1$) observed between the AEP and healthy control groups in the total lumbar spine region during maximal flexion, the only instance of the FP group operating in a similar range to the healthy control group due to the extreme flexion postures required.

The upper lumbar region, as well as the lower thoracic region appears to be a key area for distinguishing between group differences. Significant differences between upper lumbar and lower lumbar angle have previously been observed with regard to peak angles during a pick up pen, pick up box, pillow transfer and box transfer task in a female nursing cohort (n=170) (Mitchell et al. 2008). The current study similarly found that differences between upper and lower lumbar spinal angle exist in relation to subclassified groups. Mitchell et al. (2008) also observed significant differences during the pick up pen, lifting a box from the floor and squatting tasks with regard to how far the upper and lower lumbar peak angles deviated from usual standing, with a significant increase in movement in the lower lumbar region noted. The current study, in contrast, identified the lower lumbar spinal region to be a less important spinal region with regard to identifying subgroup differences, however the cohort study of Mitchell et al. (2008) varied greatly to the current study as a different approach to spinal measurement was employed (electromagnetic device) and subclassification of individuals differed (no LBP, mild LBP, significant LBP).

It is interesting that the adjustments in movement in the AEP and FP subgroups seem to be localised to very specific spinal regions, with no significant differences in the total thoracic, upper thoracic or lower lumbar regions generally across the static postures, ROM and functional tasks. A very consistent pattern has been observed which has significant implications for clinical practice and guiding postural re-education, which is relevant to specific spinal regions.

Throughout the tasks no differences were identified between the AEP and the healthy control group, with the FP group consistently showing between group differences. Previous research by Dankaerts et al. (2006d) demonstrated AEP to be the least correctly identified MCI pattern (62%) between clinicians who had been trained in the approach (with FLSP the best identified (82%)). These findings were further replicated by Fersum et al. (2009) with AEP found to be the most variable MCI to determine, with only 50% correctly identified. This shows that the AEP group may not be the most easily distinguishable subgroup, perhaps even concealing further subgroups. Alternatively the AEP group may adopt postures more similarly aligned to those of healthy individuals. It could also be that if this group is not easily determinable that some error may have occurred between clinicians in the determination of specific patient sub-groups, although this issue was addressed, in part, by the use of an 'expert' clinician. Previous results have shown agreement to be high (97%) in 'practitioners classed as 'expert' in the approach (Dankaerts et al. 2006d), however in the current study one of the practitioners was less experienced in the implementation of the MDCS. Another reason may be that these AEP patients have higher levels of kinesiophobia compared with the other MCI groups. Analysis of the DRAM scores appears to demonstrate an overall higher level risk of distress in the AEP group compared to the FP group, however this is not reflected in the kinematic results as this patient group appear to have adopted similar strategies to the healthy control group during the functional tasks. Therefore this suggests the AEP to potentially display a differing psychosocial profile to the FP group, whereby the underlying pain mechanisms may differ between groups (Linton 2000).

A major advantage of the current study results in contrast to previous literature evaluating spinal kinematics of MCI subgroups, using the MDCS (Astfalck et al. 2010b; Dankaerts et al. 2006c; Van Hoof et al. 2012) is the comparatively large sample size used. This previous literature has shown significant between group differences with only a small sample size thus suggesting that there may be a moderate to large effect size when evaluating sagittal spinal angle in these patient groups. This study further supports these previous findings and novel data has shown differences in both the thoracic spine and during functional tasks consistently, with a much greater sample size.

Dankaerts et al (2009) established a reportedly accurate (96.4%) statistical model using data from the lower lumbar and total lumbar spinal angle capable of correctly subclassifying patients from usual

standing, usual sitting, slumped sitting, forward bending and return and backward bending activities. However the results of the current study found no differences in the lower lumbar region and few observed differences in the total lumbar region. Conversely, differentiation between sub-groups was primarily established in the upper lumbar and lower thoracic spinal regions in the current study. These differences are likely to be due mainly to the differences in methodological approach. Dankaerts et al (2009) uses an electromagnetic device rather than a 3D optoelectronic system. However, the results presented in the current study are in part supported by Astfalck et al. (2010b) who found differences in the upper lumbar region during sitting postures. It could therefore be theorised that the statistical model may need to be developed in light of this new information to include the upper lumbar and lower thoracic spine as discriminating kinematic variables. This new information obtained in this study suggests that as clinicians we should not only be focused on static postures as part of clinical objective assessment, but should also incorporate functional activities. No single task was highlighted to be preferential in discriminating between groups, suggesting evaluation of a range of functional activities may be optimal to observe kinematic differences in the thoraco-lumbar spine. This approach to objective assessment is already integral to the MDCS assessment (O'Sullivan 2005). It is clear that functional tasks are performed differently by FP and AEP subgroups, especially with regard to the FP groups who appear to operate in much greater flexion in the spinal regions between the T6 and L3 spinal vertebrae.

The evaluation of gender as a covariate between groups (AEP, FP, heathy) was also explored for the kinematic results (Table 36) as well as for the sEMG data. Although fewer significant results were observed when gender was considered as a covariate, interestingly significant differenes were still consistently apparent in the lower thoracic spine throughout most functional tasks indicating this spinal region to be a key region for attention in the manifestation of NSLBP MCI regardless of gender differences. This is an interesting and novel finding not previously explored in the literature and it is clear that differences are observed in both the upper lumbar and lower thoracic spine independently of gender. Both genders are however represented in each group indicating that clinically, gender should not influence the clinician in determining MCI classification, but instead kinematic differences in the thoraco-lumbar region during functional activities as well as postures should be a focus for assessment. However the issue of gender representation in the subgroups is a factor for consideration for future research to ensure group are balanced with regard to gender, or that gender is taken into account in the analysis as it may overestimate the number of observed significant differences.

8.3.5 Summary – Kinematics

Spinal postures operating primarily at end range movement have been suggested to be potential risk factors for LBP onset (Burton et al. 1989) which is supported by the MDCS, and subsequently the spinal kinematic results obtained in the current study. Although it is acknowledged that a substantial proportion of individuals in each NSCLBP group operated in ranges within those limits observed by the healthy control group. Consistent patterns of spinal movement have been noted between groups (AEP, FP and healthy control) throughout all functional tasks and postures. These have been consistently observed in the upper lumbar and lower thoracic spinal regions to suggest that the area between T6 and L3 appears to be the key region where NSCLBP individuals with direction specific MCI operate differently between groups (AEP and FP). Additionally this region is often able to discriminate between the FP group and healthy individuals. This is the first study to demonstrate this difference in spinal kinematics in the thoracic spine, although direction specific differences in SPS have been identified in these subgroups previously (Sheeran et al. 2012).

Importantly, the current study results highlight the need for consideration of subdivided spinal regions. Clinically, this suggests that therapists should assess and consider spinal posture into the thoracic spinal region as well as evaluating spinal motion throughout functional tasks. Additionally, clinicians should be aware that this is a region where end range spinal posture may be a contributory factor to underlying pain mechanisms and as such should be key to their assessment of the entire spine rather than a focus solely around the lumbopelvic region. Interestingly, as outlined by the inclusion criteria, all individuals report pain below the level of T12, however differences are consistently observed in the lower thoracic (T6 to T12) region suggesting that compensations occur higher up the spine in response to pain in the lumbar region. Although some significant differences were observed between the AEP and FP groups in the total lumbar region, these were directly attributable to the contributions from the upper lumbar spinal regions alone as no differences were observed in the lower lumbar spinal regions. Gender also appears to be an influencing factor for spinal kinematic differences, which needs consideration when developing future study designs.

Further analysis of the results is warranted at a later date to further explore factors that may influence extreme postural range (e.g. pain, fear of movement). To date no other studies have explored spinal movement during functional tasks in subclassified NSCLBP individuals. This information is therefore of value to the current understanding of biomechanical differences in NSCLBP MCI subgroups and can assist in informing the development of specific postural re-education strategies for subclassified individuals with NSCLBP.

8.4 Electromyography

Levels of muscular activation in the trunk were evaluated using sEMG amplitudes (%SMVC) of the bilateral TrA/IO, EO, sLM and LT musculature during a series of functional tasks. The results of the analysis for the test re-test reliability of the bilateral trunk muscle amplitudes will be discussed first (between the AEP, FP and healthy control group), followed by a discussion of the results obtained during the functional tasks for the bilateral (%SMVC) amplitudes.

8.4.1 EMG - Within-Day Reliability

As a preliminary analysis, reliability for bilateral (right and left) sEMG data across 3 trials was established, however wide variation in the results was observed. Across all functional tasks test re-test reliability for trunk muscle activity varied dramatically with ICC values ranging from poor (0.191) to excellent (0.970) across all 3 groups (AEP, FP, healthy control). The abdominal musculature (TrA/IO, EO) demonstrated generally moderate reliability scores (EO: ICC 0.641 to 0.970, TrA/IO: ICC 0.329 to 0.940), however the SEM values were highly variable (EO: SEM 3.9 to 19.1 degrees; TrA/IO: 7.3 to 37.5) demonstrating wide variability with regard to performance. SEM scores may be reflective of alterations in an individual's movement strategy, rather than technical error with regard to the tool, which may impact upon reliability measures. As well as the established issues with sEMG of the trunk (e.g. increased subcutaneous fat, cross-talk) there may also be interference from the device placement. All subjects were requested to wear the sEMG on a belt around their waist (sat over the left hip), which may have increased noise interference around the abdominal region. Similarly a number of tasks involved flexion i.e. during the pick up pen (bend) task, thus increased noise interference may be an influential factor. Variability was observed to be greater in the sLM and LT musculature with ICC values varying from poor to excellent across tasks (0.247 to 0.968, and 0.191 to 0.934 for the sLM and LT muscles respectively). SEM values for sLM ranged from 3.8 to 23.6, and 4.2 to 22.2 for LT muscles.

The use of SMVCs, rather than MVCs should also be considered, as SMVCs are likely to vary dramatically between patients depending on pain and fear of movement, despite being identified to be more reliable than MVCs in CLBP populations (Dankaerts et al. 2004). Despite the wide ranges observed in ICC across the musculature, overall, 81.6% of the left sided musculature and 87% of the right sided musculature produced ICC results > 0.5 across all groups and tasks, indicating good overall within-day reliability (Landis and Koch 1977).

Consistent with the current protocol, Hopkins (2000) noted that for repeated measures of reliability at least 3 trials should be undertaken (with a sample of 50 subjects), although it could be argued that a greater number of trials would be advantageous. Due to the time required to complete data processing for each subject and the potential for symptom provocation, a greater number of repetitions would not have been feasible for this study. A pragmatic approach was taken to ensure successful study completion however repeating this study with greater subject numbers and trial repetitions would be advantageous to further support or negate these findings.

8.4.2 EMG – Tasks

Significant between group differences for mean normalised sEMG amplitudes (%SMVC) in the sLM musculature were only observed between the AEP and healthy control groups in the step up, reach up and box replace tasks on the right sided musculature. This observation is reflected in a general trend between the AEP and healthy control groups in sLM activation throughout other functional tasks including the pick up pen, stand-to-sit and box lift tasks although these did not reach significance ($p<0.1$). Hyperactivity of the trunk musculature in the AEP group has been previously proposed (O'Sullivan 2005). In support of O'Sullivan's clinical observations in all instances the AEP group demonstrate greater muscle activation compared to the healthy control group, indicating potentially increased co-contraction of the right sLM musculature throughout all functional tasks, which may be indicative of hyper-vigilant tendencies.

The results of the within-day test re-test reliability demonstrated normalised sEMG amplitudes to be variable across repeated functional tasks with differences. For the right sided musculature significant differences between the AEP and healthy control group were observed in the sLM during the step up and down, stand-to-sit and box replace tasks ($p<0.05$), although a non-significant trend ($p<0.1$) was also observed during all other functional tasks for the sLM musculature except for the pick up pen (bend and return) tasks. This may be due to the asymmetrical nature of the functional tasks. For example the step up and down was performed with the participant choosing a self-selected leading leg and the box replace task was always performed with the trunk in a flexed right-rotated position. Additionally only 5 NSCLBP subjects (2 AEP and 3 FP) reported left sided pain therefore this may influence the differences observed between left and right sEMG normalised amplitudes during the functional tasks.

Additionally in the right-sided musculature significant differences between the AEP and healthy control groups were also observed in the right EO muscles during the box lift task. This task is conducted with the trunk in rotation, a primary muscle action of the EO musculature, thus it appears that during this rotated (and flexed) lifting posture the right EO is significantly more active over the whole task in the AEP group compared to the healthy controls. As discussed previously the box rotation tasks were performed asymmetrically with the lifting component utilising left trunk rotation, which may explain the significantly different unilateral results observed.

Conversely, the left-sided sEMG results demonstrated fewer significant between group differences. Significant differences were observed between the FP and healthy control groups in the left TrA/IO musculature during the stand-to-sit tasks only ($p<0.0167$) with the FP group exhibiting greater overall

left TrA/IO activation in these groups compared to the healthy control group. Although a similar trend was observed during the sit-to-stand task this narrowly missed significance (p=0.023). Left sLM was also, similarly to the right-sided results, noted to demonstrate significant between group differences during the stand-to-sit task between the FP and healthy control group (0.009) and a non-significant trend also observed between the AEP and healthy control groups (0.030). As discussed previously these between side differences may be influenced by the subject demographics for pain location (Table 13) as few individuals reported left sided pain.

Silfies et al (2009a) suggest reduced trunk extensor endurance to be a potential explanation for an alteration in movement strategy observed during a bilateral forward reaching task in a cohort of MLBP subjects. It could be suggested these altered LBP movement strategies, in comparison to a healthy cohort, may encourage abnormal spinal loading to preclude on-going pain provocation in this population. The current study results show that during unilateral reaching significant differences in right sLM muscle activation were demonstrated (AEP compared to healthy individuals). This pattern of hyperactivity of the paraspinal musculature has been previously identified during functional activities in LBP populations (compared with healthy control subjects) (Arena et al. 1989). In the reach task shelf height was set to a comfortable reaching height, thus it may be that the task did not place a great demand on the trunk musculature, but was more aligned to shoulder girdle and upper limb motion rather than trunk involvement. The task employed by Silfies et al (2009a) also differs significantly as a bilateral task compared to the unilateral nature of the task in the current study. Additionally the focus of Silfies et al (2009a) is muscle endurance of sLM thus the degree to which these results are comparable is limited.

Previous studies evaluating bilateral EO and ES muscle activity during sit-to-stand, box lifting and flexion activities found that left EO activity was significantly reduced in a sub-acute LBP group compared to healthy subjects (Svendsen et al. 2013). However other studies have demonstrated no correlation between EO muscle activity and LBP (Ferreira et al. 2004). Despite the difference in performance of the box lifting task, compared to the symmetrical box task described in Svendsen et al's (2013) study, the current study identified right EO (but not left EO) to demonstrate significant differences between the AEP and healthy control groups. This suggests that consideration of each side is important in asymmetrical tasks.

Further, an interesting observation of Shum et al's (2005a) work was significantly increased time taken for the LBP group to complete a sit-to-standing task compared with healthy individuals, which is likely to impact upon muscular control and fatigue. Although not directly explored in the current study (and an important avenue for future data exploration), speed of movement may have some bearing on the increases in right sLM activity observed (in AEP compared to healthy controls) and

increased left IO activity (in FP compared to healthy controls) observed although these trends were not identified to be statistically significant..

Previous studies evaluating trunk muscle activity in classified NSCLBP MCI subgroups are currently limited to static postures. Dankaerts et al. (2006a) evaluated trunk muscle activity during usual and slumped sitting postures in subclassified groups. Similar to the current results, no differences in EO were identified. Although a difference was observed in right EO during the box lift task in the current study this may possibly be due to the rotational element of the activity (as discussed previously) whereas the static nature of the postures evaluated by Dankaerts et al. (2006a) may not have sufficiently activated EO to observe between group differences . However significant differences between the AEP and both the FP and healthy control groups with regard to TrA/IO, ICLT and sLM were observed ($p<0.05$) by Dankaerts et al. (2006a). In the current study only TrA/IO was observed to demonstrate significant differences during the stand-to sit trials indicating that, hypothetically, habitual sitting and standing end range postures may play a contributory role to dysfunctional TrA/IO activation rather than differences in control through range of movement. TrA/IO is widely believed to demonstrate delayed anticipatory onset in the presence of acute pain (Hodges 2001; Hodges et al. 2003b; Hodges and Richardson 1998) although this has been disputed (Mannion et al. 2012). The results of the current study further reflect a degree of potential dysfunction in TrA/IO activation in the presence of chronic pain as observed previously although it should be acknowledged that in contrast to previous studies evaluating anticipatory onset of TrA (Hodges 2001; Hodges et al. 2003b; Hodges and Richardson 1998), the current study evaluated overall amplitude muscle activity. Further analysis of the sit-to-stand-to-sit tasks with reported NRS scores may go some way to further exploring any potential link between self-reported pain and increased muscular activity of the TrA/IO in the presence of pain. However, only one significant between group difference was observed in the current study and the limitations of the positioning of the TrA/IO electrodes and the task must not be underestimated. Sit-to-stand-to-sit, as well as the pen pick up tasks, require significant trunk flexion, which may interfere with the electrodes, thus increased noise artefact within the sEMG recording may also be a factor for consideration. The use of fine-wire EMG would be advantageous in future studies to minimise these factors.

Dankaerts et al. (2006a) additionally noted that when LBP subgroups were pooled the NSCLBP group demonstrated a significantly greater activity in the ICLT and sLM musculature. Visual inspection of the descriptive results (mean and standard deviations) reveals that in the sLM musculature (mean, right and left), in both the FP and AEP groups consistently demonstrated higher %SMVC sEMG amplitudes compared to the healthy control group although often these differences were not found to be significant. A larger sample size may be required to increase the power of the study. Due to technical difficulties in the data collection, many sEMG trials were omitted due to poor quality data

thus these results can only be treated as preliminary at this stage. Issues with the use of sEMG of trunk musculature are discussed in sections 2.6.2 and 6.7.2. However, it may be of interest to conduct further analysis of the sEMG data to pool the NSCLBP subgroups to identify whether these between group differences as observed by Dankaerts et al. (2006a) exist in the sLM and potentially other trunk musculature. Dankaerts et al. (2006a) only evaluated static postures whereas the current study evaluated functional activities. These functional tasks can be conducted utilising many possible movement strategies, thus movement variability will be greater than found in static sitting tasks. This may be a further explanation as to why fewer between group differences were observed in the current study and why no differences between the FP and healthy control group were identified in contrast to Dankaerts et al. (2006a).

The current study findings highlight the difficulty of evaluating trunk muscle activity, and reflect inconsistencies in muscle activation previously observed in these patient populations. Sheeran et al. (2012) identified no significant between group differences (FP, AEP and healthy control) in sLM during usual sitting although significantly increased activity in sLM in the FP group compared with the healthy control group was observed in standing. However differences were identified in EO and TrIO between the both the FP and AEP groups when compared with the healthy control group ($p=0.002$, $p=0.006$ respectively). In contrast, Dankaerts et al. (2006a) identified differences in abdominal musculature (EO, TrA/IO) between a pooled NSCLBP and healthy control groups ($p=0.001$, $p=0.004$ respectively).

Kaigle et al. (1998) noted that intervertebral motions and trunk mobility were significantly less in LBP patients with regard to ROM. In their study FRP was demonstrated in the healthy control group by a 78% decrease in lumbar ES muscle activation full flexion whereas in the LBP subjects, only a 13% reduction in muscular activation was noted, with the majority of LBP subjects demonstrating no reduction in lumbar ES activation at all. They suggest that persistent muscle activation may restrict intervertebral motion as a protective mechanism of the neuromuscular system to increase local spinal stability and thus protect dysfunctional passive spinal structures from pain provocative movement. Hodges et al. (2013) further identified that net trunk muscle activity ($P < 0.021$) increased during the presence of pain however as this was determined in acute pain this may represent a different underlying mechanism compared to the current study. Although the MCI subjects evaluated in the current study had full active ROM objectively it is clear from the kinematic results they did not use the same ROM as healthy individuals. However it should also be noted that the current screened for hypo-mobility using PPIVMs, which are considered to be a crude and insensitive method (Hicks et al. 2003) thus it could be that individuals with hypomobility were incorrectly included in the final analyses.

Fear-avoidance may be one theory for this phenomena however currently limited evidence exists to support an association between fear-avoidance and increased muscle activity during lumbar spinal flexion (Airaksinen et al. 2006). During the most flexed trials in the current study (i.e. pick up pen trials), no significant between group differences were observed, indicating that all groups operated with similar muscle activity levels, thus it may be that spinal flexion activities may be inappropriate activities to determine differences in muscle activity between healthy and symptomatic cohorts. It would however be of interest to explore muscle activation patterns in those individuals with high TSK (fear-avoidance) scores within the current cohort.

Some correlation between increased muscle activity and catastrophising has however been observed previously in CLBP populations (Svendsen et al. 2013; van der Hulst et al. 2010b). Some NSCLBP individuals were observed to score highly on the DRAM in the current study. It would be of interest to further explore relationships between muscle activation levels and anxiety scores from this data set in future work to establish whether there is a link and whether the subgrouping MDCS approach is able to discriminate between individuals in these domains.

8.4.3 Summary – Electromyography

An interesting observation of the current study is the difference between the muscle activity and kinematic findings between groups. No differences were observed between the AEP and healthy control groups with regard to spinal kinematics throughout the functional tasks, to suggest that both AEP subjects and healthy control subjects may operate in similar patterns of spinal movement. However significant between group differences for muscle activity were observed between the AEP and healthy control groups, with the AEP group demonstrating significantly higher activation of the right-sided sLM and EO musculature during specific tasks (step up, reach up and box replace). Additionally this pattern was seen as general, albeit non-significant trend, throughout other functional tasks (return from picking up a pen, stand-to-sit and box lift). This was not evident however in the left sided musculature). The majority of subjects included in this study reported central or right sided LBP, with only 10% of NSCLBP subjects reporting left sided pain (Table 13), which may indicate muscle guarding responses of the sLM musculature over the site of pain.

In contrast, the left sided musculature demonstrated changes between the FP and healthy control groups in the TrA/IO and sLM musculature, however this was only evident during the stand-to-sit activities, although a non-significant trend was also observed during sit-to-stand (TrA/IO). In light of TrA/IO producing no other significant results in any other activity or on the right side, this observation is less clearly explained. It may be that this activity, with increased hip flexion in sitting,

may cause increased interference in the sEMG electrodes, especially considering that the sEMG 'box' is placed over the left hip. The FP group were demonstrated to be heavier with more flexed spinal postures in sitting thus potentially increasing this potential error due to increased 'noise' from increased trunk flexion and abdominal tissue. However it should also be acknowledged that although increased trunk muscle activity has been shown to be a key feature in the presence of pain, responses are highly variable and unique to the individual (Hodges et al. 2013) and thus the results obtained may further reflect this variability between individuals. Fewer significant results were similarly identified when gender was considered as a covariate between the groups.

Airaksinen et al. (2006) found conflicting evidence to support the ability of sEMG to be able to accurately differentiate NSCLBP subjects from healthy control subjects as well as for use in monitoring rehabilitation outcomes, suggesting sEMG to be inappropriate for clinical use. However the findings of the current study suggest to an extent that sEMG is sensitive enough to detect differences in unilateral muscle activity between subgroups of NSCLBP subjects and healthy controls, albeit only between AEP and healthy control groups, where significantly increased values in the AEP group were observed. However due to the lengthy application procedures sEMG of trunk musculature is currently not feasible for use in a clinical environment. Although the clinical use of sEMG as a diagnostic tool for LBP is considered unfeasible, sEMG as a research tool to evaluate muscular dysfunction in CLBP populations is considered to be an acceptable approach (Pullman et al. 2000).

It is also interesting to note that the AEP group displayed a significantly greater distress profile (DRAM score: 29.8 compared to 22.7 respectively, $p=0.027$) and consisted of a higher percentage of female participants. Both these factors have been identified as factors influencing non-specific LBP (Kent and Keating 2008) and may therefore be hypothesised to contribute to the hypervigilant muscle activity response observed. The AEP group also had a larger proportion of individuals classified as high risk on the STarT Back tool indicating that these groups differ in multiple ways, not only in kinematics and EMG alone, which will impact on the direction of the targeted interventions developed.

It is clear that sEMG can add value with regard to understanding trunk muscle activity during functional tasks in NSCLBP subgroups. However substantial limitations to the approach remain and thus the results must be interpreted tentatively.

8.5 Overall Summary

These findings provide greater insight into the neuromuscular control of movement in subclassified groups of NSCLBP patients. The findings suggest that distinct differences in spinal kinematics are evident between the FP and AEP, and FP and healthy control groups in the thoraco-lumbar region (especially between T6-L3) not only during static postures but also during functional tasks. It can be tentatively inferred that the FP group adopt postures and movement behaviours most distinct from the AEP and healthy control subjects. This finding further supports and validates the clinical manifestations of the FP disorder as proposed in the MDCS (O'Sullivan 2005). Understanding the underlying mechanisms for the AEP group is less clear. It appears that these individuals posturally move differently to the FP group however do not differ significantly from healthy control subjects. This may be due to the limited sample size, less clinically distinguishable characteristics in the MDCS, within group gender representation, or, alternatively, differences in underlying pain mechanism. The sEMG results interestingly suggest that potentially the AEP group may adopt maladaptive muscle guarding strategies with increased unilateral trunk muscle co-contraction of the sLM, potentially leading to muscular fatigue and pain provocation (van Dieen et al. 2003). These findings are interesting, however it is acknowledged that further work to evaluate these phenomena in larger cohorts is required.

8.6 Research Implications

There are a number of research implications that can be derived from the study findings. The study results firstly support the existence of MCI subgroups (AEP and FP) as proposed by the MDCS (O'Sullivan 2005). This further validates the classification approach, not only for the subjective assessment of patient presentation and objective assessment of static postures, but highlights that objective assessment of functional activities may also be of valuable in aiding the identification of more homogeneous subgroups. These findings also support the need for future research to identify specific subgroups of NSCLBP individuals due to the risk of observing a ‘wash out’ effect (Rose 1989).

The novelty of these results is that it is evident that these subgroups operate in distinct ranges of motion in specific spinal regions (especially with regard to spinal posture between the T6 and L3 spinous processes). This is of value for future research as it highlights the need for the thoracic spine to be evaluated in conjunction with the lumbar spine, as well as the need to subdivide the spine into specific spinal regions in order to evaluate biomechanical between group differences.

Another implication for research, as has been described in detail previously, are the challenges of recording trunk muscle activity using sEMG, however despite the potential limitations, subgroup analysis did reveal differences between the AEP and healthy control groups in the right-sided sLM musculature, thus indicating sEMG to be able to detect between group differences in muscle activity and further reinforcing that subgroup differences in muscle activity do exist. Future work should seek to consider both spinal kinematics and muscle activity in the evaluation of MCIs where interactions between pain and people with different postures may differ.

Few studies to date have evaluated functional movements of the spine. The current study demonstrated that the functional movement protocols used were sufficient to reveal subgroup differences, and thus could be replicated in future work. Laboratory based research may not be conducive to individuals performing activities as they would naturally, however, the consistent and significant findings of altered movement patterns between subgroups and healthy control subjects suggests that this protocol and environment was appropriate and could be replicated in future studies.

The findings of the systematic review suggest that there is a paucity of literature to document and demonstrate reliability and validity of spinal marker sets. In order to ensure research methodology is robust, and ultimately detect differences that are clinically important, the reliability and validity of such methodological approaches should be clearly investigated and reported. Future work should include this information, or reference suitable sources, as routine practice. New wearable technologies that can record 3D motion analysis wirelessly are also needed to evaluate functional spinal movement effectively over prolonged time periods.

Finally, the reliability study established good within-day and between-day reliability of this protocol (functional tasks) for healthy individuals. This was subsequently replicated for test re-test reliability of both the spinal kinematics and trunk muscle activity (sEMG) across all subgroups to establish reliability of the approach and demonstrate the degree to which these patterns of movement behaviour are consistently observed. The findings further support the protocol utilised and show consistency of human movement in both healthy individuals and subgroups of NSCLBP subjects thus the protocol could be replicated in future work to evaluate how these subgroups respond to specific intervention.

8.7 Clinical Relevance and Implications for Clinical Practice

A number of areas considered within this thesis are relevant for clinical practice. The results of the study further validate the MDCS through demonstration of between subgroup differences during functional tasks, as well as ROM and static postures. Although the MDCS is becoming more

commonly recognised in clinical practice as an integral aspect of clinical reasoning and subclassification approach for NSCLBP management, the need for clinicians to undertake training courses in the approach may be impacting upon its widespread clinical implementation. This is potentially due to the time commitment and training required to become proficient in accurately identifying these MCI subgroups.

With regard to total spinal angles during the static postures, differences were only observed in the total lumbar spine in usual sitting highlighting the need for clinicians to look beyond general postures as observation of total posture may be limited in clinical value. However, the results of the current study suggest that distinct differences in spinal posture are apparent between these two groups, not only with regard to static postures (when evaluated in sub-divided spinal regions), but also during functional activities, which can easily be observed by clinicians as an integral aspect of patient assessment. This new information emphasises the importance of functional assessment as part of the clinical objective assessment, especially with regard to the classification system. It is clear that functional tasks are performed differently by FP and AEP subgroups, especially with regard to the FP groups who appear to operate in much greater flexion in the spinal regions between T6 to L3. These groups therefore require targeted interventions to be developed clinically to address these specific regional spinal differences. Interventions should be focussed on changing these MCI behaviours to optimise loading and reduce excessive protection strategies such as muscle guarding and movement avoidance. Patient, or MCI, specific education is another important aspect for these subgroups to eliminate these conditioned movement behaviours.

An unexpected aspect of the study was the pattern of between group differences identified with regard to spinal kinematics and trunk muscle activity. Significant differences in muscle activity were identified between the AEP and healthy control group with increased muscle activation in unilateral musculature (right sided sLM) observed in the AEP group, with the FP group generally demonstrating no significant differences with the healthy controls. Conversely, with regard to spinal kinematics, it was the FP group that significantly differed from the AEP group, and often also the healthy control group, with the AEP and healthy control groups generally appearing to operate in more similar ranges of motion. These findings are of great interest clinically as they suggest varying mechanisms of motor control to be potentially predominant in different subgroup classifications (i.e. increased muscle co-activation in AEP; and spinal posture differences in FP) thus specific interventions for these subgroups may also somewhat differ with a greater emphasis potentially required on not only postural, but functional, re-education in the FP group to increase overall spinal lordosis, whereas the AEP group may require a greater clinical focus on mechanisms to reduce muscle hyper-activity. It could be argued that normalisation of spinal posture during functional activity may be a key aim for each subgroup despite these underlying differences in pain provocation mechanism. For example

normalisation of excessive kyphotic postures in the FP group may be beneficial in avoiding excessive end-range strain on passive spinal structures, whereas normalisation of hyperlordotic thoraco-lumbar posture in the AEP group may have a secondary influence on dampening hyperactivity of the trunk musculature. The research also highlights the need for clinical strategies to be focussed on re-training and re-education functional movement rather than posture alone as it is clear that MCI patients adopt such postures throughout functional activity.

It is acknowledged that trunk muscles cross these spinal regions where differences are observed in kinematics (notably lower thoracic and upper lumbar). Muscle re-training interventions may need to focus on these regions in order to have an overall impact on muscle hyperactivity lower down the spine. There may also be a need to palpate and assess differences in bilateral muscle activity during movements. It is also not known whether changes in muscle activity influence spinal kinematics or vice versa. Further research is warranted on larger subject cohorts to explore these theories.

CB-CFT has been shown to be effective in reducing disability and pain in subclassified groups (AEP, FP) of NSCLBP individuals (Fersum et al. 2013). The findings of this current study clearly demonstrate the distinct patterns of movement behaviour exhibited during functional activities thus re-education of functional movement appears paramount to ceasing the continual aggravation of potentially pain provocative spinal postures. Therefore the requirement for CB-CFT is further highlighted by the current study results. Additionally this information can be utilised to improve our knowledge regarding how function is affected in subgroups, which can be used to further develop and refine CB-CFT interventions.

An aspect of NSCLBP to be considered is the likelihood of individuals presenting with age-related changes and osteoarthritic (or degenerative) changes in the spine (Adams and Dolan 2005). It is likely that a significant proportion of subjects may display these underlying structural changes radiologically, thus it would be of interest in future research to evaluate whether the degree of degenerative change observed impacts on MCI subgroup classification and functional patient presentation. Significant degenerative changes are identified in most spines by the age of 40 years (Schmorl and Junghanns 1971) with some degenerative changes observed in all spines by the age of 50 (Vernon-Roberts 1988). In the current study the average age of the participants was 43.7 years in the AEP group and 41.0 years in the FP group thus it is likely that the vast majority of subjects would display some spinal degenerative changes. The MDCS suggests that MCIs occur irrespective of underlying degenerative processes. A small (n=20: 11 AEP, 9 FP) sample of the subjects used in the present study had radiologically identifiable changes on x-ray, however the total number of patients with radiology records was too low for comparative subgroup analysis to be conducted in the present study. If the hypothesis stands, that MCI subgroups move similarly and display the same subgroup

characteristics as those individuals without OA changes, this may further support the current guidance on refraining from radiology for NSCLBP (Airaksinen et al. 2006) and implies that these patients can be managed in a similar way to other MCI subgroup patients, irrespective of underlying structural changes.

In order to further monitor how these patient groups respond to novel targeted interventions, devices which can monitor postural change over prolonged time periods and provide biofeedback to patients to correct postural extremes of range are required, such as the BodyGuard™ posture monitoring system (O'Sullivan et al. 2011). However novel tools that can evaluate multiple spinal regions need to be developed for clinical monitoring of patient progression (or regression) between sessions.

8.8 Limitations and Methodological Issues

Despite every effort to ensure a robust methodological approach to the work presented in this thesis a number of limitations are evident which are to be discussed.

Two of the subgroups proposed by the MDCS have been evaluated (AEP and FP), however it is acknowledged that these two groups only constitute a proportion of the MDCS MCI subgroups and only provide a select insight into the wider NSCLBP population. Despite the patients being recruited from a large patient pool, strict inclusion and exclusion criteria were applied limiting the number of individuals eligible for participation in the study to only those who present with AEP or FP MCI patterns, It is acknowledges that other MCI patterns exist (PEP, FLSP, MDP) (O'Sullivan 2005). To the best of the author's knowledge, no studies have, to date, evaluated spinal kinematics and muscle activity in the MDP, FLSP or PEP MCI subgroups, as these patient presentations appear to occur more infrequently in the general population compared to AEP and FP subjects. It has been previously shown in one study that clinicians trained in the MDCS are able to consistently identify these patient groups, despite only small numbers of patients presenting with such MCI patterns (Fersum et al. 2009). Additionally, in a case report of a MDP MCI patient, Dankaerts et al. (2007) also demonstrated that targeted treatment for the impairment (CB-CFT) led to normalisation of motor control and reduction in movement related fear and pain. However, intervention outcomes in the PEP or FLSP subgroups has to date not been reported. Although patients presenting with these MCI patterns were initially included into the data collection sessions, insufficient numbers for comprehensive analysis were achieved, due to the fact that these presentations are less commonly observed, thus only the results for the AEP and FP MCI patients are presented in this thesis. Further research exploring whether these patterns demonstrate altered kinematics and muscle activity levels are required.

Clinical subclassification of patients into MCI subgroups was performed as a consensus approach between a clinician trained in the MDCS and an 'expert' clinician. This approach of utilising two clinicians to determine subgroup classification aligns with previous research (Astfalck et al. 2010b; Dankaerts et al. 2006a, c), with the use of an expert clinician defined as the 'gold standard' (Dankaerts et al. 2006d) however the risk of bias is still a factor for consideration.

There is some research to suggest that subjects with a previous history of LBP, tend not to achieve spinal mobility levels comparable with healthy control subjects regardless of the fact that these subjects are pain-free (Burton et al. 1989). This observation was noted primarily in younger male subjects in Burton's (1989) study. Although the current study stipulated no history of LBP within the past two years for the healthy control group (as well as a stipulation for no previous history of back pain with radiating symptoms with no time period specified) it is possible that this may not have been a comprehensive enough exclusion criteria as subjects with previous LBP episodes which resolved prior to the previous 2 years may still exhibit biomechanical dysfunction as a result (MacDonald et al. 2010). Future studies should consider employing exclusion criteria including any previous LBP episodes until more is understood regarding the implications of previous episodes of LBP on long-term biomechanical adaptive changes. However realistically this would make healthy recruitment very difficult. Despite this argument, the healthy control group routinely adopted ROM postures consistently demonstrated to lie between the flexion and extension ranges indicating that the healthy control subjects suitably differ from symptomatic, although it is accepted that in many instances significant differences were not found.

Total lumbar range of motion has been shown in previous studies to vary according to the time of day tested. Ensink et al. (1996) evaluated lumbar ROM in a CLBP cohort (n=29). They found that total lumbar ROM, measured using an inclinometer and the modified-Schober sign, was found to significantly increase as the day progressed from morning to evening, when measured at 3 regular intervals throughout the day. In contrast, extension of the lumbar spine was found to be independent of time of day recorded. In the current study participants attended the research laboratory anytime between 9am and 6pm, dependent on patient, researcher and laboratory availability therefore this is variable which could not be accounted for due to resources and needs to be taken into consideration when interpreting the results.

Human error with regard to marker misplacement for measurement of spinal kinematics using Vicon® is an issue for consideration in the current study design. Despite the use of an experienced clinician performing all surface palpation of anatomical landmarks and marker placement, the potential for a degree of human error remains an issue. Previous studies have identified this, especially with regard to the location of L4 and the PSIS' which have found to be landmarks inconsistently identified

(Simmonds and Kumar 1993). Additionally, following piloting of the marker set it was observed that the system was unable to distinguish between closely placed markers thus the final marker set was developed to utilise a final spinous process marker at L4 with a 'virtual' S2 marker calculated as the midpoint between the PSIS'. These factors combined provide some rationale for the paucity of significant between group differences observed in the lower lumbar spinal region which used both the L4 and virtual S2 marker to complete the angle calculation, thus the findings for this region may reflect some inaccuracies, potentially explaining why results may differ with data previously reported (Dankaerts et al. 2006c). Some tasks requiring extreme extension ROM at the lumbar spine would have led to markers moving closer together and thus increased 'cross-over' of markers was observed during these trials, as previously noted by Whittle and Levine (1997), thus the accuracy of the extension trials may have been impacted upon.

Marker placement devices have been developed to minimise the issue of human error in marker placement (between sessions) through recording 3D co-ordinates of marker placement for replication during subsequent sessions (Noehren et al. 2010; Telfer et al. 2010). This approach has been shown to be more accurately replicate marker placement in the lower limb (Noehren et al. 2010). Although this study was based on a single session, this may be a consideration for future longitudinal studies where kinematic evaluation is required in order to evaluate intervention outcomes and long-term follow up. Technical approaches for the measurement of spinal movement are also continually improving. It has been discussed that spinal movement research needs to move away from skin mounted sensors towards a more widespread use of methods such as video fluoroscopy (Baker 2006) to more accurately calculate true joint motion, however the limitations of such an approach (e.g. financial expense, exposure to radiation) must also be considered.

The inherent methodological issues with 3D motion analysis must also be considered. System errors can occur through discrepancies in camera placement and resolution, as well as marker placement error, skin movement, errors in marker labelling and gap filling (Dorociak and Cuddeford 1995). Although significant steps and quality assurance checks were undertaken for each of these parameters these errors may still have some impact on the overall results obtained.

As highlighted previously, reported reliability of sEMG of the trunk musculature is conflicting. The test re-test reliability results for the sEMG amplitudes during the functional tasks demonstrated wide variances in SEM values indicating variation in errors across tasks and muscles (Table 37; Table 38). Although every effort was made to minimise additional 'noise' interference, the dynamic nature of the tasks may have exacerbated sEMG signals; for example via subcutaneous fat, or clothing interference. To ensure sEMG recordings were as reliable as possible all preparatory procedures were followed as per SENIAM guidelines (Freriks and Hermens 1999).

Despite these highlighted limitations, all possible actions to minimise such issues were implemented to best of the author's knowledge.

8.9 Recommendations for Future Research

8.9.1 Further Analyses of the Current Data Set

The study design was observational in order to explore potential differences in sub-grouped MCI NSCLBP patients with healthy control subjects, thus the current results can be considered to be a preliminary overview of kinematic and muscle activity behaviour in these populations. However, the volume of data collected was substantial and thus further analysis of the data set to explore subgroup differences in greater depth is possible.

There are alternative approaches to exploring spinal movement in patients with NSCLBP as opposed to spinal angle. It is acknowledged that range of motion assessment using angles only provides insight into a small part of movement analysis and that understanding alternative kinematics such as acceleration and velocity to develop a more in-depth understanding of how individuals move during functional tasks may be of value (Tsang et al. 2014). This may be especially important in understanding how interventions addressing motor control and movement dysfunction can be developed and targeted, for example to understand whether patients perform movement more slowly in the presence of pain. Velocity of movement of the lumbar spine has been shown to be reduced in LBP cohorts during functional tasks (Shum et al. 2007b) as well as in the cervical spine in individuals with chronic neck pain during a weight transference task (Tsang et al. 2014). Within the context of this study it was deemed important to ensure the parameters explored reflected the body of work previously conducted evaluating kinematics within this NSCLBP subgrouped population (using the MDCS) to ensure the data was comparable (Astfalck et al. 2010b; Dankaerts et al. 2006c). Additionally the proposed CB-CFT approach for addressing such impairments centres around the re-education of functional movement in direction specific patterns. For this reason spinal angles during functional tasks can provide important information regarding spinal positioning and posture and can offer information with respect to whether FP and AEP spinal positioning (and angle) differs when conducting the same task. However velocity and acceleration of the spine during the functional tasks could also be established from the existing data set and would be an interesting area for future evaluation to better understand how temporal parameters of spinal motion influence movement behaviour in subclassified back pain groups. Re-analysis of the data using more advanced analytical techniques such as principal component analysis (PCA) would also enable a more full exploration of

the patterns of spinal movement over the whole trial, rather than a single value, to be evaluated. This may expose between group differences in overall movement behaviours during functional activities. There are several approaches to analysing normalised sEMG data during functional activities. More sophisticated sEMG analysis techniques could also be explored to look at how sEMG amplitudes differ during different aspects of tasks (e.g. time), or evaluate peak activity, to provide greater understanding of how trunk muscle activity changes throughout functional tasks. Evaluation of onset-offset muscle timing across the entire functional task could be argued to be a more specific approach to understanding recruitment patterns of the trunk muscles in NSCLBP (Marshall and Murphy 2003; Tsang et al. 2014). Similarly further evaluation of periods of muscle co-contraction may provide useful information regarding how different muscles interact during functional tasks (Silfies et al. 2005). In the current study the volume of normalised sEMG data generated was very large due to the number of tasks evaluated therefore normalised amplitude was utilised to provide a 'snapshot' of muscle activity over the whole of a task to determine between group differences. Normalised amplitude sEMG has been evaluated in other literature exploring static postures in NSCLBP subgroups (using the MDCS) a similar methodological approach was employed to ensure that the results were comparable (Astfalck et al. 2010b; Dankaerts et al. 2006a). However it is acknowledged that few significant differences were established in this study between the trunk muscles, thus it would be of value to re-analyse the data using analysis of onset and offset times for sEMG to understand in greater depth how muscle activity may differ between groups, especially if the data were to be evaluated alongside velocity of spinal movement. Co-activation would also be of clinical value to explore to understand the potential 'bracing' mechanisms employed by the trunk muscles.

Fine wire EMG, may also be a useful methodological approach in future studies to evaluate subgroup differences in the deeper musculature such as deep fibres of LM, TrA and iliopsoas. Quadratus lumborum and rectus abdominis are also muscle groups that may play a role in trunk stability and motor control (Andersson et al. 1996; Bogduk et al. 1992; De Franca and Levine 1991; Ng et al. 2002c) and thus may be of interest for future NSCLBP subgroup research.

A further aspect for consideration in future analyses is angle of inclination of the pelvis. All spinal angles in the study were reported relative to the pelvis, and the pelvis has previously been identified to play a key role in influencing lumbar spinal posture (Youdas et al. 2000). Due to the presence of pelvis markers, this information could be further explored using the current data set.

It would be possible to conduct further analysis on the current data set using a repeated measures ANOVA with all tasks and groups as factors. In the contrast analysis it would be possible to explore if a consistent difference between the group values is observed. This would increase the power of the

analysis and allow inferences to be made regarding the ROM offsets observed between the groups (hierarchy of tasks).

Evaluation of sagittal spinal angles alone may be insufficient to sensitively identify between group differences in these patient cohorts due to the directional differences between groups. Additional further analysis of the AEP and FP subjects in both the frontal and transverse planes of motion would provide further insight into the potentially complex movement strategies employed by these patients, and healthy controls, during functional tasks. For example whether a difference between the FP and AEP with regard to thoracic rotation during the box rotational tasks, or bending to pick a pen up off the floor could be explored. This approach would also enable comparisons to be drawn with other MCI subgroups in future. For example frontal plane kinematic analysis would likely be required in patients presenting with FLSP due to the maladaptive movement being proposed to be evident in the frontal plane. Similarly multidirectional pattern may require analysis of a complex movement strategies incorporating sagittal, frontal and transverse plane spinal movement analysis to ascertain a comprehensive overview of the disorder, and the potentially multiple manifestations of the impairment.

The biopsychosocial framework is integral to the MDCS. Therefore, clinically, better understanding of the characteristics (e.g. pain, fear of movement, disability) of patients who adopted postures beyond the confidence interval ranges of the healthy control subjects would be of considerable interest. It may be that these patients exhibit greater pain levels or fear of movement where the patients display the greatest predominance towards end range postures throughout the tasks, which may give a clearer insight into how the proposed postural maladaptive behaviours specific to each subgroup may develop.

Pain onset and duration during full ROM and functional tasks would be of value to investigate how motor control influences pain through range. It has been previously observed, in spondylolysis and spondylolisthesis patient cohorts, that pain was commonly reported through range (rather than at end range) (O'Sullivan et al. 1997). These findings suggest dysfunctional motor control, rather than strain of passive spinal structures at end range, to be a primary pain mechanism for LBP groups. Evaluation of this data may address this hypothesis to further inform targeted intervention development through specific functional movement re-education.

8.9.2 Future Research

Cortical effects, as result of CNS changes due to stress or fear, have been proposed as a potential mechanism for alterations in spinal motor control (Flor 2003; Flor et al. 1997; Hodges and Moseley 2003). No differences in patient reported measures were observed between groups, with the exception of DRAM scores that were higher in the AEP group. However the physical mechanisms underlying the FP and AEP pain presentations appear to be different. In order to comprehensively understand why patients continue to move in pain provoking movement patterns is yet undetermined and further research investigating cortical effects, through brain imaging techniques may be warranted in this patient population (Dankaerts and O'Sullivan 2011).

Although subgroup differences for spinal kinematics were observed, data was only recorded during a single session. How these patient groups operate physically during prolonged activities and the factors influencing performance are undetermined. Future work, incorporating methodology such as continuous postural monitoring would enable insight into monitoring usual patient behaviour and could evaluate carry-over between therapeutic sessions and longer term movement behaviour change. This information could then potentially be used to inform long-term patient management; for example optimal numbers of therapeutic sessions required, and economic and cost-benefit analyses.

The current study has established that between group differences in spinal kinematics and muscle activity exist during functional activities, as well as further supporting previous findings of differences during static postures (Astfalck et al. 2010b; Dankaerts et al. 2006a, c; Sheeran et al. 2012) to further validate the MDCS (O'Sullivan 2005). However it is undetermined how these maladaptive behaviours develop. For example whether NSCLBP MCI patients have longstanding, established poor postural control, which exacerbates a pain response; or alternatively whether individuals develop these maladaptive behaviours as a result of pain is yet to be determined. If it is the latter, understanding at what stage of the disorder these maladaptive behaviours become established could be crucial to implementing timely intervention. Future research evaluating change in spinal kinematics and trunk muscle behaviour over time from initial presentation with acute pain onset could help to establish which patients recover and which patients go on to develop these long-term maladaptive behaviours. Future work is also warranted to explore if underlying (radiologically identified) osteoarthritic changes influence MCI, as it is hypothesised that these individuals may present with the same maladaptive MCI changes regardless of underlying osteoarthritis of the spine.

Although this study primarily evaluates the biomechanical attributes of individuals LBP experience it could be argued that this only reflects one potential dimension of the disorder as multiple other factors may also influence pain (such as pain in adjacent regions, fitness levels, weight, respiratory issues, continence, balance and co-ordination, beliefs etc.). However, the MDCS considers all dimensions of LBP presentation and is proposed to be used as a clinical reasoning approach rather than a one-size-fits-all model and allows scope for the therapist to use their own clinical judgment. The current study findings do however further contribute knowledge of the functional biomechanical differences these subgroups may be presenting with. Despite this, it is also acknowledged that further work is required to more fully understand how the different dimensions interact in order to comprehensively manage the challenge of LBP (Rabey et al. 2015).

Finally, future work is required to evaluate the impact of targeted subgroup intervention. Classification-guided and CB-CFT interventions have been shown to be effective for AEP and FP subgroups (Fersum et al. 2013; Sheeran et al. 2013). Large scale, multi-site RCTs are required to further support these preliminary studies to further validate the use of CB-CFT approaches for subclassified MCI NSCLBP populations.

9 CONCLUSIONS

Currently little research exists to quantify spinal movement behaviour during everyday functional activities in either healthy cohorts or subjects with CLBP. This is due in the main to the huge variation in habitual human functional movement, the lack of understanding and implementation of subgrouping approached for NSCLBP and the complexities of accurately quantifying motion of both the lumbar and thoracic spine during dynamic activity. This thesis has attempted to address these gaps in the current literature to explore biomechanical differences between subgroups of NSCLBP subjects who present with MCI of the spine compared to functional movement patterns in a healthy cohort.

Significant between group differences have been consistently demonstrated throughout static postures, ROM and during functional tasks, particularly in the lower thoracic and upper lumbar spinal regions with regard to sagittal spinal angle. These findings highlight the importance of considering the spine in subdivided regions rather than whole regions (i.e. lumbar, thoracic), where distinct regional differences in movement patterns between groups may be missed. This is the first time the thoracic spine has been considered simultaneously with the lumbar spine with regard to sagittal spinal angle during functional tasks. The differences consistently observed with in the lower thoracic region further highlight the need to consider the region between the T6 and L3 spinous processes both clinically and in the research environment to obtain a comprehensive picture of biomechanical differences in movement strategies. The current findings are further validation of the MDCS and provide a platform from which to further develop and refine targeted intervention and specific postural and functional re-education for subclassified groups of NSCLBP patients.

Despite notable limitations of the use of sEMG for recording muscle activity in the trunk musculature some significant differences were observed to identify distinct unilateral differences in muscle activation patterns between NSCLBP subgroups and healthy control subjects. This information highlights where these between group differences in motor control adaptations may lie and thus may be valuable for the development of targeted interventions for MCI subgroups.

The methodological approaches utilised in this study have been shown to be reliable and valid when tested within-day for spinal kinematics across all groups (AEP, FP, healthy control), although sEMG reliability was more variable. Within- and between-day movement variability in healthy individuals has also been established to demonstrate that healthy individuals move consistently throughout functional tasks when performed consecutively and, to a lesser extent, when repeated between days.

It is acknowledged that the data analysis and results presented in this thesis are preliminary findings. Further in-depth evaluation of the data obtained will enable a more comprehensive understanding of the movement behaviour throughout different aspects of the functional tasks and aligning spinal kinematics and electromyography data to the patient reported measures obtained will enable further understanding of the presentation of MCI subgroups in contrast to healthy matched subjects. This will provide invaluable insight into potential links between psychosocial factors and biomechanical presentation.

This research has substantial implications for clinical practice. There is strong evidence that individuals with NSCLBP do move differently in specific directional patterns when performing functional movement, which is closely linked to the direction of subjectively reported aggravating and easing factors. These consistent significant findings in the thoraco-lumbar region demonstrates the importance of this area in discriminating between subjects, when evaluated throughout functional activities. Therefore it is recommended that physical examination incorporates assessment of the thoraco-lumbar spine during functional activities, with treatment strategies incorporating targeted functional re-education of movement in the thoraco-lumbar region. For the FP individuals this would be targeted at the functional re-education of the thoraco-lumbar spine from a habitually flexed posture to enhancing control in a more neutral spinal position. Conversely, re-education for the AEP individuals would be focussed around neutralising thoraco-lumbar postural control to a less extended spinal position. Despite all patients displaying full active range of lumbar spine movement objectively during assessment, direction specific differences in spinal kinematics were observed across a range of functional activities, thus highlighting the importance of assessing dynamic, functional movement in the assessment of NSCLBP. The assessment of the pelvis relative to the thoraco-lumbar spine will need to be considered by therapists as this is likely to influence the positioning of the thorax. Intervention should also be focussed around not only postural, but functional re-education of thoraco-lumbar movement. The results support the MDCS as a valid framework for subgrouping NSCLBP, and thus the results of this work can inform the further development and refinement of CB-CFT interventions.

Technological advances in tools to quantify spinal movement over prolonged periods (for example daily pattern of movement) will enable a greater depth of understanding of movement behaviour in NSCLBP. Therefore the further development of wireless postural monitoring tools, which are capable of monitoring both lumbar and thoracic motion is also warranted for future clinical utility, whereby functional movement can be evaluated not only in the laboratory setting on a single occasion but to provide an overview of how an individual moves posturally over a 24 hour period.

Although it is acknowledged that no single approach to subgrouping of NSCLBP is all encompassing these results do support the clinical implementation of the MDCS. It may be that these subgroups can be subclassified further using other subclassification strategies (e.g STarTBack) to further refine the clinical management of these patient populations.

In summary, there appears to be a significant difference in the biomechanical presentation of MCI subgroups of NSCLBP where patient reported measures fail to elicit differences with regard to psychosocial profile, pain and disability. The AEP group appear to adopt and maintain more extended postures throughout static postures and daily tasks in comparison to the FP group who conversely adopt more flexed postures during these activities. What is more unexpected is that these differences are consistently identified in the region of T6 to L3 and the underlying causes for this are unclear. There is also a difference in muscle activation observed in the right sided sLM musculature during a number of functional tasks between the AEP and healthy control group and significant differences between the FP and healthy control group with regard to TrA/IO and sLM activity during stand-to-sit tasks.

This doctoral thesis explores the biomechanical differences of subclassified groups of NSCLBP subjects with healthy controls to contribute substantially to the current body of knowledge regarding NSCLBP. The importance of employing validated subclassification approaches to NSCLBP research has been further highlighted, as well as demonstrating significant biomechanical differences in specific, consistently replicated, spinal regions not only during static postures but during functional tasks. Specific differences have also been explored between these subgroups and healthy individuals demonstrating key differences that may enable specific targeted interventions to be realised for these patient groups. This thesis has further highlighted the complexity of NSCLBP and the requirement for further research in order to continually develop and refine targeted intervention strategies to improve patient outcomes in patients with NSCLBP.

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APPENDIX I

Literature Review

Search Strategy

Search Strategy

The search was conducted by using the following relevant, medically based, databases: AMED, Cinahl, PEDro, Cinahl, Scopus, PubMed, Medline via Ovid and the Cochrane library.

Keywords included for literature searching include:

Lumbar / Thoracic / Spine / spinal

Sub-classification / sub-group / classification

Multidimensional classification

LBP / Low back pain / CLBP / NSCLBP / non-specific low back pain / mechanical low back pain

Functional activities / activities of daily living / ADL / stairs / lift / sit / stand / reach / bend / step

Flexion / extension / rotation

Trunk muscle / muscle activation / muscle activity

External oblique / internal oblique / tranversus abdominis / lumbar multifidus / multifidus / erector spinae / longissimus thoracis

Motor control / dysfunction

Posture / spinal movement / movement / motion

Kinematics / biomechanics / spinal angle

Validity / reliability

Flexion relaxation phenomenon

Cognitive functional therapy

Oswestry disability / ODQ / ODI / TSK / Tampa scale of kinesiophobia / VAS / visual analogue scale / STarT Back / IPAQ / international physical activity questionnaire / DRAM / distress and risk assessment method

Electromyography / EMG

Spinal marker / marker set

APPENDIX II

The Multidimensional Classification Approach

Outline of the Multidimensional Classification Approach

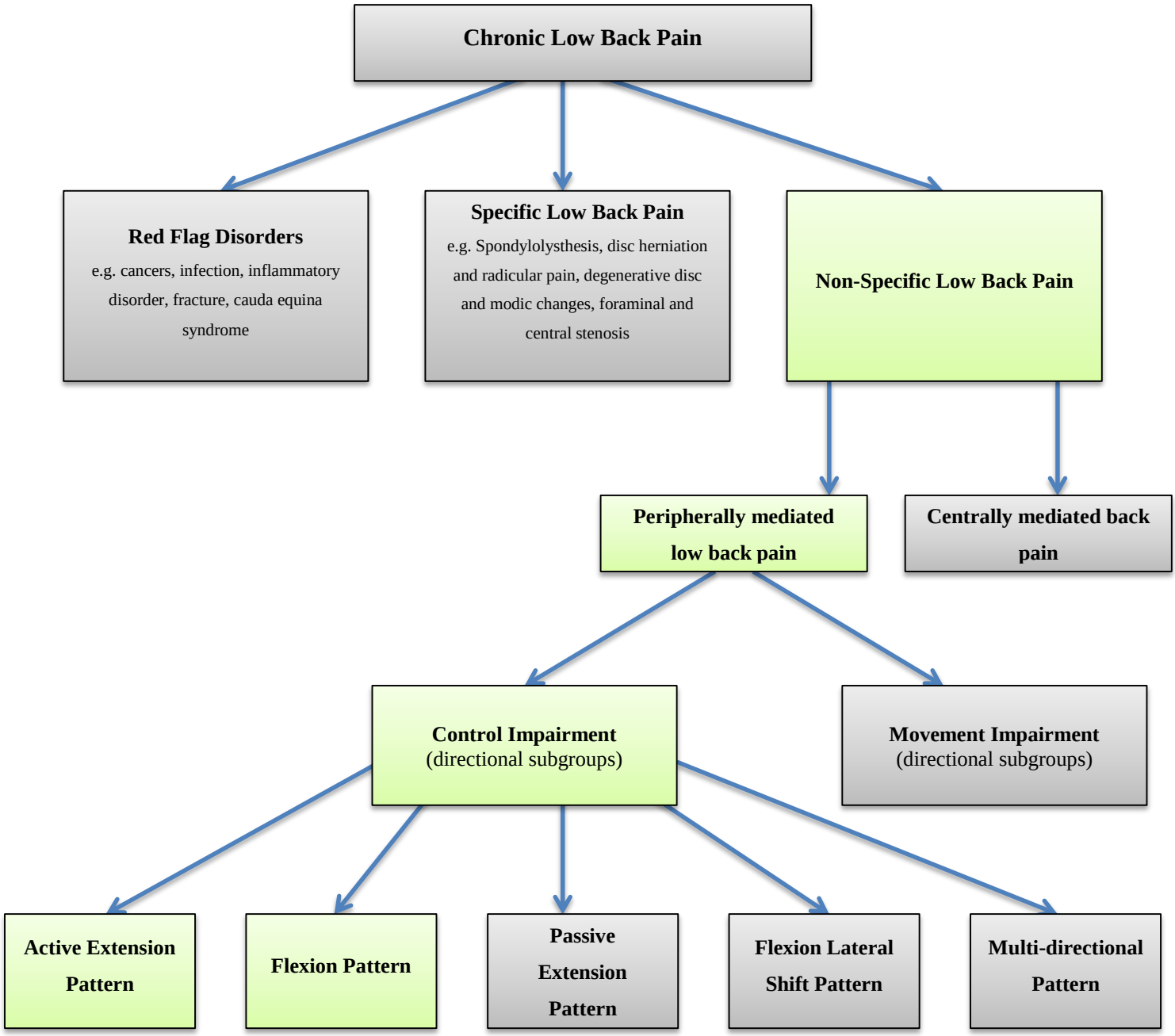
Subjective and Objective Criteria

Posture and movement analysis and control tests

Proposed management approaches for classified NSCLBP sub-groups

Inclusion and exclusion criteria

Outline of O'Sullivan's Classification System



Overview of the Multidimensional Classification Approach (MDCS). Adapted from O'Sullivan (2005) and Fersum et al (2009)

Control Impairment Patterns – Subjective and Objective Criteria

Clinical features of the five control impairment patterns as described by O'Sullivan (2004) (reproduced from Dankaerts et al. (2006))

Control Impairment	Definition	Provocative Postures and Activities	Easing Postures and Activities	Posture and Movement Analysis	Specific Posture and Movement Control Tests
Flexion Pattern	MCI of the lumbar spine with a tendency to flexion strain (loss of segmental lordosis) at the symptomatic segment. Flexion pain disorders are associated with functional loss of motor control into flexion resulting in an excessive abnormal flexion strain.	All flexion-related postures (e.g. slouched sitting) and functional activities (forward bending, cycling) are commonly reported as being painful.	Extension postures/ activities where the lumbar spine is lordosed (e.g. standing, sitting with a lumbar roll, walking).	Tendency to present with a loss of lumbar lordosis during sitting and standing postures. The pelvis is often positioned in posterior pelvic tilt. During all functional tasks the same tendency to have a loss of lordosis at the 'symptomatic level' is noted. Forward bending movements commonly reveal a tendency of an early 'loss of lower lumbar lordosis' (lumbar curve reversal). Similar loss of lordosis is accentuated in other functional tasks like sit- to-stand, squatting and gait. This is associated with an increased lordosis in the upper lumbar and lower thoracic spine.	Inability/ lack of motor control to anterior rotate pelvis and extend lower lumbar spine independent from thorax during above-mentioned aggravating postures/ movements.
Active Extension Pattern	MCI around the lumbar spine with a tendency to hold the lumbar spine actively into extension.	All extension-related postures (standing, erect sitting) and functional activities (carrying out overhead activities, fast walking, running and swimming) are commonly reported as being painful. Also commonly reported as a provocative activity is forward bending (with the key feature here being the tendency to hold the lumbar spine into segmental hyperextension).	Flexion postures/ activities where the lumbar spine is flexed (e.g. crook lying, slouched sitting).	Tendency for the lumbar spine to be actively held into segmental hyper-lordosis at the symptomatic segment during upright sitting and standing postures. During all functional tasks such as sit to stand, squatting and forward bending the same tendency to hyper-lordose at the 'symptomatic segment' is noted. Forward bending movements commonly reveal increased hip flexion and a tendency of a late 'loss of lordosis' (beyond mid range of flexion) or no lumbar curve reversal. Return to neutral from a forward bended position reveals an early hyper-lordosing of the spine at the symptomatic segment.	Inability/ lack of motor control to initiate a posterior pelvic during above-mentioned aggravating postures/ movements.

Flexion/Lateral Shifting Pattern	MCI around the lumbar spine with a tendency to flex and laterally shift at the symptomatic segment.	Reaching and rotating in one direction in association with flexion postures and / or movements.	Relief in extended or lordotic postures, stretching to the opposite side from the shift, shift correction (contra-lateral glide from pelvis).	Similar to the flexion pattern there is a loss of lumbar segmental lordosis at the affected level with the key feature here an associated lateral shift at the lower lumbar spine level. Minimal precipitation of their spine might deviate into a lateral shift position. e.g. the lateral shift is accentuated when standing on the foot ipsi-lateral to the shift. Sagittal spinal movements reveal a tendency to laterally deviate during flexion and this is commonly associated with an arc of pain. Tests like 'sit to stand' usually reveal a typical flexion pattern presentation (see above) plus a tendency towards lateral trunk shift during the movement with increased weight bearing on the lower limb on the side of the shift.	Inability/ lack of motor control to anterior rotate pelvis and extend lower lumbar spine independent from thorax during above-mentioned aggravating postures/movements with an associated lateral deviation
Passive Extension Pattern	MCI around the lumbar spine with a tendency to passively over-extend at the symptomatic segment of the lumbar spine.	Similar to the active extension pattern all extension-related postures (standing, erect sitting) and functional activities (carrying out overhead activities, fast walking, running and swimming) are commonly reported as being painful.	Flexion postures/ activities where the lumbar spine is de-lordosed (e.g. crook lying, slouched sitting).	Tendency for patients to stand into a sway-back posture (thorax posterior to the pelvis) with a segmental hinging at the symptomatic level. Forward bending is often pain free, but on return to neutral they tend to over-extend at the symptomatic level (hinge into extension) and sway pelvis anterior.	Inability/ lack of motor control to extend the thoraco-lumbar spine above the symptomatic segment with a tendency to hinge into extension at this segment.
Multi-directional Pattern	Multi-directional MCI around the lumbar spine	Multi-directional nature of this pattern often reveals pain all weight bearing postures and functional activities.	Difficulty to find relieving positions during weight bearing	Patient may assume a flexed, extended or laterally shifted spinal posture, and may frequently have to alternate them. Excessive segmental shifting and hinging may be observed in all directions, with associated 'jerky' movement patterns and reports of 'stabbing' pain on movement in all directions with observable lumbar erector spinae muscle spasm.	Patients have great difficulty assuming neutral lordotic spinal postures, with over shooting into flexion, extension or lateral shifting postures.

Multidimensional Classification Approach - Posture and movement analysis and control tests

Posture and Movement Analysis for each proposed control impairment pattern (reproduced from O'Sullivan (2004))

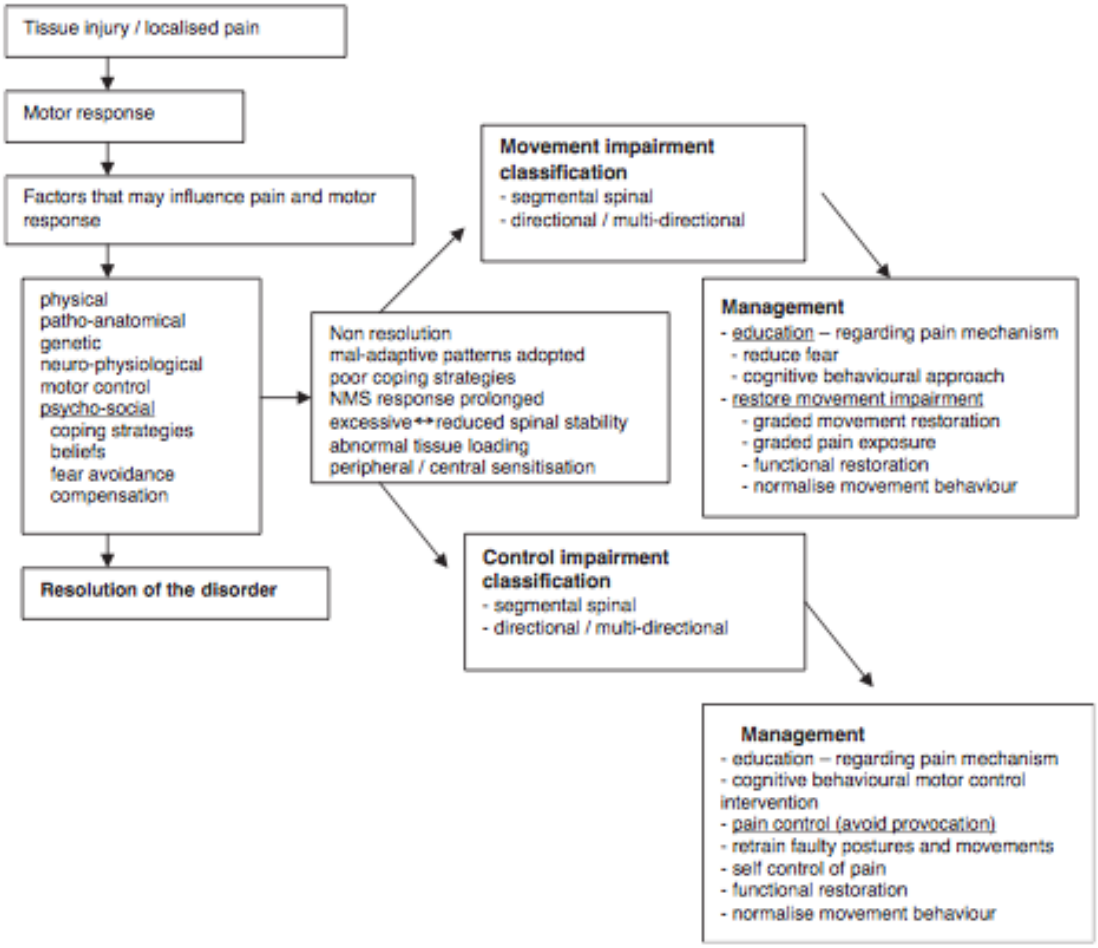
	Flexion	Lateral shift/ flexion	Extensin (passive)	Extension (active)	Multidirectional
Standing posture	Flattened lumbar lordosis at 'unstable' segment	Flattened lumbar lordosis at 'unstable' segment Lateral shift	Thorax posterior to pelvis Increased segmental lordosis at 'unstable' segment	Thorax anterior to pelvis Increased segmental lordosis at 'unstable' segment	Variable
Stabilizing strategy	Thoracic ES Upper abdominal wall (RA, EO, upper TO)	Asymmetrical thoracic ES, quadratus lumborum, upper, abdominal ipsilateral to shift	Upper abdominal wall (RA, EO, upper IO)	Lumbar ES, psoas +/- LM	Co-contraction / guarding of global trunk muscles
Spinal segment loading	Anterior	Anterior / lateral	Posterior	Posterior	Variable / alternating
Forward bending in standing	Increased flexion at 'unstable' segment Extension thoraco-lumbar spine Increased posterior pelvic rotation (+/- are of pain)	Increased flexion and lateral deviation of trunk above 'unstable' segment	-	Delayed or loss of reverse lordosis (delayed or absence of flexion relaxation) Hyperextension of 'unstable' segment Excessive interior pelvic rotation	Increased flexion at 'unstable' segment
Return to neutral from forward bending	Extension thoraco-lumbar spine 'Unstable' segment remains flexed (+/- are of pain)	Extension thoracolumbar spine 'Unstable' segment remains flexed and deviated (+/- are of pain)	Tendency to overextend, at 'unstable' segment, and sway pelvis; anteriorly on assuming upright position	Tendency to hyperextend 'unstable' segment early on return to upright position (+/- are of pain)	Variable / alternating
Lumbar:hip ratio	3:1	3:1	-	1:3	3:1
Centre of rotation of spinal segment	Anterior	Anterolateral	-	Posterior	Anterior
Backward bending in standing	Increased extension above 'unstable' segment Reduced extension at 'unstable' segment	Increased extension above 'unstable' segment with lateral deviation Reduced extension at unstable segment	Increased extension at 'unstable' segment Reduced extension above 'unstable' segment Excessive pelvic away	Increased extension at 'unstable segment Anterior pelvic rotation	Increased extensin at 'unstable segment
Lumbar:hip ratio	1:3	1:3	3:1	3:0	3:1
Centre of rotation of spinal segment	Anterior	Anterolateral	Posterior	Posterior	Posterior
Single leg stand / gait		Lateral shift of thorax, relative to pelvis +/- trendelenberg	Anterior away of pelvis relative to thorax +/- Trndelenberg Internal hip rotation	Posterior away of pelvis relative to thorax Internal hip rotation	Variable / alternating
Squat	Increased flexion at 'unstable' segment Posterior pelvic rotation	As with flexion pattern + Lateral deviation	-	Increased extension of 'unstable' segment Anterior pelvic rotation	Variable / alternating
Lumbar:hip ratio	3:1	3:1	1:3	-	Variable
Sitting	Flexed lower lumbar spine Posterior pelvic rotation Extended thoraco-lumbar spine	As with flexion + deviation	Slumped posure	Hyper-lordotic lumbar posure Anterior rotation of pelvis	Variable / alternating
Sit-Stand	Increased lexion at 'unstable segment Extension thoraco-lumbar spine Increased posterior pelvic rotation (+/- are of pain)	Increased flexion and lateral deviation of 'unstable' segment (+/- are of pain)	Hyperextension of 'unstable' segment and excessive anterior elvic, away on assuming erect, position	'Unstable' segment maintained in hyper-lordosis throughtout the movement (+/- are of pain)	Either flexed or extended
Lumbar:hip ratio	3:1	3:1	-	1:3	Variable / alternating

Specific Posture and Movement control tests for each proposed control impairment pattern (reproduced from O'Sullivan (2004))

	Flexion	Lateral shift/flexion	Extension (passive)	Extension (active)	Multidirectional
Standing posture correction (for loading pain)	Anterior rotation of pelvis Increase lower lumbar lordosis	As with flexion + correct deviation	Correct away posture	Reduce lordosis / posterior pelvic rotation / relax thorax	As indicated
Forward bending correction (for movement pain)	Anterior rotation of pelvis Increase lower lumbar lordosis Flex thoracolumbar spine	As with flexion + Correct deviation	-	Enhance posterior pelvic rotation and lumbar flexion Enhance return to neutral with gluteal activation	As with flexion
Backward bending correction (for movement pain)	-	Correct deviation	Reduces away Enhance extension of upper lumbar spine with control of sway and posterior pelvic rotation to minimize hinging	Enhance posterior pelvic rotation via hips	As with 'passive' extension
Single leg stand correction (for loading pain)	Enhance interior rotation of pelvis Increase lower lumbar lordosis	Correct deviation with focus on keeping head central with weight transference via hip	Correct postural sway aligning thorax over pelvis	Reduce lordosis / posterior pelvic rotation / relax thorax	As indicated
Squat correction (for loading +/- movement pain)	Enhance interior rotation of pelvis Increase lower lumbar lordosis	Correct deviation with focus on keeping head central with weight transference via hip	-	Reduce lordosis/ posterior pelvic rotation / relax thorax	As indicated
Sitting correction (for loading pain)	Anterior rotation of pelvis Increase lower lumbar lordosis Relax thorax	As with flexion + correct deviation	-	Reduce lordosis / posterior pelvic rotation / relax thorax	As indicated
Erect and slump sitting	Erect sitting associated with thoracolumbar extension. Unstable segment emains in flexion	As with flexion + deviation	Hyperextension unstable segment	Erect sit associated with hyperlordosis Inability to slump sit	Hyperextension lower lumbar spine
Neutral zone re-positioning test Place into neutral lordosis- (a) fully slump and ask to return to neutral position	Tendency to reposition into flexion at unstable segment	Tendency to reposition into deviation	Tendency to reposition into extension	Tendency to reposition into extension	Variable
(b) maintain neutral lordosis and bend forward through the hips	Tendency to flex at unstable region	Tendency to flex and laterally deviate at 'unstable' region	Tendency to extend at 'unstable' region	Tendency to hyperextend lumbar spine	Variable
Sit-stand Place spine in neutral lordosis--assess ability to hold neutral spinal position during task (for loading and movement pain)	Tendency to flex at 'unstable' region	Tendency to flex and laterally deviate at 'unstable' region	Tendency to extend at 'unstable region	Tendency to hyperextend lumbar spine	Variable
Sit-stand--Single leg loading	-	Excessive lateral shift of thorax over the pelvis when loading the affected side	-	-	-
Anterior posterior pelvic rotation (supine)	Inability to anterior rotate pelvis and extend low lumbar spine independent of thorax	As with flexion + asymmetrical pelvic rotation	Inability to extend thoracolumbar spine independent of pelvis	Inability to posterior rotate pelvis and flexion lumbar spine independent of hip flexion	
Lumbopelvic lateral rotation independent from hip and thorax (supine)	-	Inability to rotate lumbo--pelvic region independent of thorax and hip--on side of shift	-	-	As with lateral shift
Prone hip extension	-	-	Excessive segmental extension Absence of gluteal activation	Excessive lumbar lordosis and trunk rotation Minimal hip extension	Excessive segmental extension
Four-point kneeling Anterior / posterior pelvic rotation	Inability to anterior rotate pelvis and extend lumbar spine independent of thorax	As with flexion with associated lateral deviation	Inability to extend thoracolumbar spine independent of pelvis and 'unstable' segment	Inability to posterior rotate pelvis and flexion lumbar spine	Variable
Lateral leg lower (supine)	-	Inability to maintain lumbopelvic position on side of shift Asymmetrical rotation	Tendency to hyper-extend and rotate lower lumbar spine and flex thoracolumbar spine	Tendency to hyper extend and rotate lumbar spine	Excessive rotation and extension of lumbar--pelvic region

Proposed management approaches for classified NSCLBP sub-groups

Flow chart to highlight the proposed management approaches for the movement impairment and control impairments in the MDCS (from O'Sullivan, 2005)



Inclusion and exclusion criteria for NSLBP patients with Motor Control Impairment

(from Dankaerts et al. (2006))

Inclusion criteria
A history of chronic (>3 months) LBP
Pain only located to the lower lumbar spine (L4/5 or L5/S1) with minimal radiation
Absence of impaired movement of the symptomatic segment in the painful direction of movement or loading (based on clinical joint motion palpation examination)
Associated impairments in the control of the motion segment(s) in the provocative movement direction(s)
Clear mechanical basis of disorder: specific postural and functional movements that aggravate and ease symptoms; relief of symptoms when reducing the strain to the symptomatic spinal segment in the provocation direction
Exclusion criteria
More generalized low back pain (beyond L4-5, L5-S1 region) and/or radiating pain
Dominant non-organic features (yellow flags)
Impaired movement of the symptomatic segment in the painful direction of movement or loading (based on clinical joint motion palpation examination)
Based on medical assessment (by general practitioner and/or specialist, including radiological imaging): specific diagnoses for LBP disorder (disc prolapse with radicular pain, severe scoliosis, spondylo-arthrosis, spondylolisthesis, inflammatory or other specific disorders), previous back surgery, and serious causes of LBP (red flag pathology)

[a]All features within the inclusion criteria had to be present; based on O'Sullivan (2000, 2004b).

APPENDIX III

Systematic Review

Systematic Review – Search Strategies

Critical Appraisal Tool

Systematic Review – Search Strategies

Database: AMED

1. exp Spine/
2. spine.mp.
3. spinal.mp.
4. Trunk/
5. thoracic.mp.
6. thoraco*.mp.
7. Thorax/
8. lumbo*.mp.
9. lumbar.mp.
10. pelvi*.mp.
11. Sacrum/
12. sacral.mp.
13. Back/
14. or/1-13

15. kinematic*.mp.
16. biomechanic*.mp.
17. three-dimension*.mp.
18. (3D or 3-D).mp.
19. or/15-18

20. ((movement or motion) adj3 range).mp.
21. Movement/
22. motion.tw.
23. (sagittal or frontal or transverse).tw.
24. or/20-23

25. 14 and 19 and 24

Database: Cinahl (Cinahl Plus with Full Text)

S32 S14 and S28 and S31

S31 S15 or S16 or S17 or S18 or S19 or S30

S30 (MM "Motion Analysis Systems")

S29 S14 and S20 and S28

S28 S21 or S22 or S23 or S24 or S25 or S26 or S27

S27 "transverse"

S26 frontal

S25 "sagittal"

S24 (MM "Motion")

S23 (MH "Movement/PH")

S22 motion n3 range

S21 movement n3 range

S20 S15 or S16 or S17 or S18 or S19

S19 "3D"

S18 "three-dimension*"

S17 biomechanic*

S16 biomechanics

S15 kinematic*

S14 S1 or S2 or S3 or S4 or S5 or S6 or S7 or S8 or S9 or S10 or S11 or S12 or S13

S13 (MM "Back")

S12 "sacral"

S11 (MH "Sacrum")

S10 pelvi*

S9 (MH "Pelvis")

S8 "lumbar"

S7 "lumbo*"

S6 thoraco*

S5 "thoracic"

S4 (MH "Thorax")

S3 (MH "Torso") OR "trunk"

S2 "spinal"

S1 (MH "Spine")

Database: The Cochrane Library

#1 MeSH descriptor **Spine** explode all trees

#2 MeSH descriptor **Thorax** explode all trees

#3 MeSH descriptor **Lumbosacral Region** explode all trees

#4 MeSH descriptor **Pelvis** explode all trees

#5 MeSH descriptor **Pelvic Bones** explode all trees

#6 MeSH descriptor **Sacrum** explode all trees

#7 MeSH descriptor **Back** explode all trees

#8 (Spine):ti,ab,kw or (spinal):ti,ab,kw or (trunk):ti,ab,kw or (thorax):ti,ab,kw or (thoracic):ti,ab,kw

#9 (thoraco*):ti,ab,kw or (lumbo*):ti,ab,kw or (lumbar):ti,ab,kw or (pelvi*):ti,ab,kw or (sacrum):ti,ab,kw

#10 (sacral):ti,ab,kw or (back):ti,ab,kw

#11 (#1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10)

#12 MeSH descriptor **Biomechanics** explode all trees

#13 (kinematic*):ti,ab,kw or (biomechanic*):ti,ab,kw or "three-dimension*":kw or (3D):ti,ab,kw or (3-D):ti,ab,kw

#14 (#12 OR #13)

#15 MeSH descriptor **Movement** explode all trees

#16 MeSH descriptor **Motion** explode all trees

#17 (**motion NEAR/3 range**):ti,ab,kw or (**movement NEAR/3 range**):ti,ab,kw or (**movement**):ti,ab,kw or (**motion**):ti,ab,kw

#18 (sagittal):ti,ab,kw or (frontal):ti,ab,kw or (transverse):ti,ab,kw

#19 (#15 OR #16 OR #17 OR #18)

#20 (#11 AND #14 AND #19)

Database: Embase

1. exp spine/
2. spine.mp.
3. spinal.mp.
4. trunk/
5. thorax/
6. thoracic.mp.
7. thoraco*.mp.
8. lumbo*.mp.
9. lumbar.mp.
10. pelvis/
11. sacrum/
12. back/
13. or/1-12

14. kinematic*.mp.
15. biomechanics/
16. biomechanic*.tw.
17. three-dimension*.mp.
18. (3D or 3-D).tw.
19. or/14-18

20. "movement (physiology)"/
21. motion/
22. motion.tw.
23. (sagittal or frontal or transverse).tw.
24. ((movement or motion) adj3 range).tw.
25. or/20-24

26. 13 and 19 and 25

27. limit 26 to (human and english language)

Database: Medline via Ovid ('Medline 1947 – Present')

1. exp Spine/
2. spine.mp.
3. spinal.mp.
4. trunk.mp.
5. thorax.mp.
6. thoracic.mp.
7. thoraco*.mp.
8. lumbo*.mp.
9. lumbar.mp.
10. pelvi*.mp.
11. sacrum.mp.
12. sacral.mp.
13. *Back/
14. or/1-13

15. kinematic*.mp.
16. biomechanics/
17. biomechanic*.tw.
18. three-dimension*.mp.
19. (3D or 3-D).tw.
20. or/15-19

21. ((movement or motion) adj3 range).tw.
22. *Movement/
23. motion.tw.
24. (sagittal or frontal or transverse).tw.
25. or/21-24

26. 14 and 20 and 25

27. limit 26 to (english language and humans)

Database: Medline in Process

1. spine.mp.
2. spinal.mp.
3. trunk.mp.
4. thorax.mp.
5. thoracic.mp.
6. thoraco*.mp.
7. lumbo*.mp.
8. lumbar.mp.
9. pelvi*.mp.
10. sacrum.mp.
11. sacral.mp.
12. back.mp.
13. or/1-12

14. kinematic*.mp.
15. biomechanic*.mp.
16. three-dimension*.mp.
17. (3D or 3-D).mp.
18. or/14-17

19. ((movement or motion) adj3 range).mp.
20. movement.mp.
21. motion.mp.
22. (sagittal or frontal or transverse).mp.
23. or/19-22

24. 13 and 18 and 23

Database: PEDro

NB: Single keyword term entered then results titles individually visually screened (for each keyword separately)

Keyword terms

Kinematic*

Biomechanic*

3D

3-D

three-dimension*

three dimension*

Database: Scopus

(((ABS(spine)) OR (ABS(spinal)) OR (ABS(trunk)) OR (ABS(thorax)) OR (ABS(thoraco*)) OR (ABS(lumbo*)) OR (ABS(lumbar)) OR (ABS(pelvi*))) OR ((ABS(sacrum)) OR (ABS(sacral)) OR (ABS(back)) OR (ABS(thoracic)))) AND ((ABS(kinematic*)) OR (ABS(biomechanic*)) OR (ABS("three-dimension*")) OR (ABS(3d)) OR (ABS(3-d))) AND ((ABS(movement W/3 range)) OR (ABS(motion W/3 range)) OR (ABS(movement)) OR (ABS(motion)) OR (ABS(sagittal)) OR (ABS(frontal)) OR (ABS(transverse))) AND (LIMIT-TO(SUBJAREA, "ENGI") OR LIMIT-TO(SUBJAREA, "HEAL") OR LIMIT-TO(SUBJAREA, "COMP") OR LIMIT-TO(SUBJAREA, "MULT")) AND (LIMIT-TO(LANGUAGE, "English"))

NB: all limited to abstract only with search terms, English only, limited to healthcare professions, engineering & computer science

Systematic review critical appraisal tool

(Reproduced from Brink and Louw (2011))

Item 1: If human subjects were used, did the authors give a detailed description of the sample of subjects used to perform the (index) test on?
Why the criterion should be evaluated: The validity and reliability of a test will be affected by the sample characteristics or composition and therefore the study has to report on the sample characteristics because the validity and reliability scores will then only be applicable to that particular population. A study does not contribute to validity and reliability testing if the subjects were not recruited appropriately.
This item can be scored yes if:
1 the sample characteristics (e.g. height, weight, age, diagnosis, symptom status) were described or the manner of recruiting subjects was stated or if selection criteria were applied.
If none of the above have been described or if insufficient information was provided, select 'no'. If inhuman or inanimate objects were used, select N/A.

Item 2: Did the authors clarify the qualification, or competence of the rater(s) who performed the (index) test?
Why the criterion should be evaluated: The amount of experience of the rater(s), performing the (index) test, will influence the validity and reliability scores and needs to be explained.
This item can be scored yes if:
1 the rater(s) characteristics (e.g. qualification, specialization, amount of experience using the instrument under investigation) have been described.
If the above have not been described or insufficient information was provided, select 'no'.

Item 3: Was the reference standard explained?
Why the criterion should be evaluated: The index test scores need to be compared to the scores obtained from the reference standard in order to test validity, therefore the reference standard needs to be explained appropriately.
This item can be scored yes if:
1 the reference standard is likely to produce correct measurements;
2 the reference standard is the best method available; and
3 details (name of the instrument, references to the accuracy of the instrument) of the reference standard are reported.
If none of the above is applicable to the reference standard's description, then select 'no'.

Item 4: If inter-rater reliability was tested, were raters blinded to the findings of other raters?
Why the criterion should be evaluated: When raters have access to the findings of other raters, it compromises the quality of the reliability testing procedure by inflating the agreement among the raters, therefore blinding needs to be performed.
This item can be scored yes if:
1 it is stated that the raters were blinded to each other's findings or if a description that implies that the raters were blinded was reported.
If no information is provided then select 'no'. If intra-rater reliability was examined then select 'N/A'.

Item 5: If intra-rater reliability was tested, were raters blinded to their own prior findings of the test under evaluation?
Why the criterion should be evaluated: If raters have knowledge of their prior own findings, it will influence the findings of their repeated measurements and could inflate the rater agreement, therefore appropriate measures, depending on the characteristics or the study design of the research study, need to be applied to ensure blinding.
This item can be scored yes if:
1 rater(s) has/have examined the same subjects on more than one occasion, it should be stated whether

the rater(s) was/were blinded to the subjects they have examined previously.
If insufficient information is provided then select ‘no’. If interrater reliability was examined then select ‘N/A’.

Item 6: Was the order of examination varied?
Why the criterion should be evaluated: If the order is varied, in which the raters examine the subjects when inter-rater reliability is tested, it reduces the risk of systematic bias. If the order is varied in which subjects are examined by one rater when intra-rater reliability is tested, it reduces the risk of the rater recalling the previous test scores and reduces bias.
This item can be scored yes if:
1 the order in which subjects were tested varied between raters if inter-rater reliability was tested;
2 the order of subjects was varied when intra-rater reliability was tested.
If insufficient information is provided then select ‘no’. If varied order of examination is unnecessary or impractical (e.g. rater(s) digitizing or reading X-rays) then select ‘N/A’.

Item 7: If human subjects were used, was the time period between the reference standard and the index test short enough to be reasonably sure that the target condition did not change between the two tests?
Why the criterion should be evaluated: The index test and the reference standard should be performed at the same time; however, this is not always possible. It becomes important to know whether it is possible that the test variable did not change between the two tests, otherwise it will affect the index test’s validity performance.
This item can be scored yes if:
1 results from the index test and the reference standard were collected on the same subjects at the same time;
2 a delay between measurements occurs, it is important that the target condition should not change between measurements.
If the time period between performing the index test and the reference standard was sufficiently long that the target condition may have changed between the two tests or if insufficient information is provided then select ‘no’. If inhuman or inanimate objects were used then select N/A.

Item 8: Was the stability (or theoretical stability) of the variable being measured taken into account when determining the suitability of the time interval between repeated measures?
Why the criterion should be evaluated: For reliability, the test variable should not change between repeated measures, otherwise it will decrease the amount of agreement obtained between and within the rater(s).
This item can be scored yes if:
1 the stability of the variable is known or reported and reviewers then decide on an appropriate time interval between repeated measures (stability of a test variable can only be determined if there is a reference standard);
2 there is no reference standard, then the reviewers should agree upon the theoretical stability of the variable and decide on an appropriate time interval between repeated measures.
If insufficient information is provided then select ‘no’.

Item 9: Was the reference standard independent of the index test?
Why the criterion should be evaluated: If the reference standard and the index test are not independently performed, then the index test cannot replace the reference standard on its own.
This item can be scored yes if:
1 it is clear from the study that the index test did not form part of the reference standard.
If it appears that the index test formed part of the reference standard then select ‘no’.

Item 10: Was the execution of the (index) test described in sufficient detail to permit replication of the test?
Why the criterion should be evaluated: Variations in the execution of the reference standard and the (index) test might affect the agreement between the two tests and it is also important to be able to

replicate the same study procedure in another setting when needed.
This item can be scored yes if:
1 the study reported a clear description of the measurement procedure (e.g. the positioning of the instrument or rater, execution sequence of events);
2 citations of methodology were supplied.
The extent to which details is expected to be reported depends on the ability of different procedures to influence the results and on the type of instrument or test under evaluation.
If insufficient information is provided then select 'no'.

Item 11: Was the execution of the reference standard described in sufficient detail to permit its replication?
Why the criterion should be evaluated: For the same reason as item 10.
This item can be scored yes if:
1 the study reported a clear description of the measurement procedure (e.g. the positioning of the instrument or rater, execution sequence of events);
2 citations were supplied.
If insufficient information is provided then select 'no'.

Item 12: Were withdrawals from the study explained?
Why the criterion should be evaluated: The sample composition will influence the validity and reliability performance of the (index) test; therefore it is important to know whether any withdrawals from the sample might have changed the composition of the sample.
This item can be scored yes if:
1 it is clear what happened to all subjects who entered the study;
2 subjects who entered but did not complete the study are taken into account.
If it appears that subjects who entered but did not complete the study were not accounted for or if insufficient information is provided, then select 'no'. If inhuman or inanimate objects were used then select N/A.

Item 13: Were the statistical methods appropriate for the purpose of the study?
Why the criterion should be evaluated: The aim of validity and reliability studies is to report on an estimate of validity and reliability for the particular test and appropriate statistical methods need to be implemented in order to produce this estimate.
This item can be scored yes if:
1 the analysis is appropriate in terms of the type of data (e.g. categorical, continuous, dichotomous);
2 statistical analysis for validity studies incorporates, for example, means, differences between measurements, 95% confidence interval, ANOVA; and
3 statistical analysis for reliability studies incorporates, for example, interclass correlation coefficient, 95% confidence interval.
If the analysis is not appropriate or if insufficient information was provided, then select 'no'.

APPENDIX IV

Participant Documentation

Permission to Contact Form

Patient Information Sheet (Part 1)

Patient Information Sheet (Part 2)

Healthy Volunteer Information Sheet (Part 1)

Healthy Volunteer Information Sheet (Part 2)

Patient Consent Form

Healthy Volunteer Consent Form

Patient Recruitment Letter

Dr Helen Roberts / Dr Andrea Longman
Research Coordinators
Arthritis Research UK Biomechanics and Bioengineering Centre
Biomedical Sciences Building
Cardiff University
Museum Avenue
Cardiff
CF10 3AX
Tel: 029 20875419

PERMISSION TO CONTACT FORM

Arthritis Research UK Biomechanics and Bioengineering Centre (Arthritis Research UK BBC)

Arthritis Research UK and Cardiff University have set up the Arthritis Research UK BBC at Cardiff University. The centre is a collaborative partnership between 6 academic departments within Cardiff University, Orthopaedic Consultants, Rheumatology Consultants and Physiotherapists within Cardiff and the Vale University Health Board and Cwm Taf Health Board.

The research team is investigating normal joint biomechanics (the application of mechanical principals to the biology of the joint) to determine how this is influenced by weakness, disease or trauma to inform clinical intervention and rehabilitation. The objectives of the Centre are to look at how we can slow down the progression and possibly improve outcomes for people with arthritis.

For some of our research we need patients who have weakness, disease, suffered trauma or are undergoing surgery to take part. This may range from allowing us to have the tissue removed during surgery that would normally be disposed of after surgery so that we can look for causes of joint diseases, having an extra blood test during routine clinic visits so that we can look for indicators of disease, which may help us to pick up conditions such as osteoarthritis earlier in the future, or visiting a special laboratory to have movements in your joints measured by special cameras.

We are asking you to fill in and sign this form if you are interested in taking part in our research. Filling in this form does not mean that you have to take part, and you are free to withdraw from the research at any time, and this will not affect your standard of care and you do not have to give a reason for your withdrawal from the study. Filling in this form simply gives us permission to talk to your consultant about the reason you are seeing him or her and to contact you to tell you more about the research areas your consultant thinks that you may be appropriate for. Please be reassured that your information will be kept confidential if you sign this form.

You may be asked to take part in none, one, several or all of the separate parts of the research. If you do take part in the research, we will ask you to sign a consent form for each separate research project.

You can find out more information about the Centre from our website:

http://www.cardiff.ac.uk/arcbbc/

or from our Research Coordinator:

Arthritis Research UK BBC, Cardiff School of Biosciences, Cardiff University , CF10 3AX

Tel: 029 2087 5419
Email: robertshc@cardiff.ac.uk or longmanaj@cardiff.ac.uk

If you are interested in taking part in the research carried out in the Centre, please fill in the form below and leave it in the box provided, give to a member of you clinical team or a researcher who may be present at clinic. If you would prefer to take the form home and think about it, please send it to the Research Coordinator at the address above if you decide to take part in the research.

Please note that you may be asked at other times if you wish to take part in this or other research.

Full Name: _____

Date of Birth: _____

Hospital number (if known): _____

Address: _____

_____

_____

_____

_____

Telephone number: _____

Email address: _____

Patient NHS no (if known): _____

Consultant name (if known): _____

Joint affected: _____

Operation type (if applicable): _____

Operation date (if applicable): _____

I give permission for researchers associated with the Arthritis Research UK Biomechanics and Bioengineering Centre, Cardiff University to talk to my consultant about the reason I am seeing him or her and to look at my medical records to determine if I am suitable to take part in any of the research studies. I understand this does not mean I have to take part in any of the research studies and that I am free to withdraw at anytime.

_____ _____

Signature Date

Dr Helen Roberts / Dr Andrea Longman
Research Coordinators
Arthritis Research UK Biomechanics and
Bioengineering Centre
Biomedical Sciences Building
Cardiff University
Museum Avenue
Cardiff
CF10 3AX
Tel: 029 20875419

PATIENT INFORMATION SHEET

Assessment of joint function in patients with joint problems using three dimensional motion analysis techniques

Part one

You are being invited to take part in a research study with Cardiff University's Arthritis Research UK Biomechanics and Bioengineering Centre. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. One of our team will go through the information sheet with you. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to participate. Part 1 tells you about the purpose of this study and what will happen to you if you take part. Part 2 gives you more detailed information about the conduct of the study.

What is the purpose of this trial?

The aim of the trial is to investigate the function of joints for people with joint problems and people with healthy joints. The data can be used to develop new treatments, improve the design of joint replacements, improve rehabilitation and improve the way that motion is analysed clinically.

The study is designed to examine the effects of joint problems and any subsequent operation or other treatment (where appropriate), on the joints ability to perform daily tasks (such as walking, lifting a cup etc).

Do I have to take part?

It is up to you to whether or not to take part. If you do decide to take part you will be given this information sheet to keep and after you have had enough time to read through it, be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time or without giving a reason. A decision not to take part or to withdraw at any time will not affect the standard of care you receive. Should you decide not to take part, you do not have to provide a reason for this decision.

What will happen to me if I take part?

You have been asked to take part in this as you have a problem with your joint that we are interested in looking at with this technique. It will allow us further insight into the nature of joint function and

pain that people with your joint problem encounter. You may also been asked to take part so we can examine a non affected joint so we can compare it to the joint problem.

If you wish to take part you will assessed either in the Cardiff University School of Engineering, Human Motion Analysis Laboratory or in the Cardiff University School of Healthcare studies (SOHCS) Research Centre for Clinical Kinaesiology (RCCK) or in the relevant clinical settings. The number of times we would ask you to attend would depend on the joint problem; we will discuss this with you when going through this information sheet. Each session will last a maximum of three hours.

Data will be kept securely for a minimum of 15 years in accordance with good research practice and data protection regulations imposed by Cardiff University in accordance with the Data Protection Act 1998. All data obtained during the study will remain confidential. Access to data will only be available to the investigators attached to the Arthritis Research UK Biomechanics and Bioengineering Centre at Cardiff University.

If new information becomes available, we may invite you to take part in a follow-up study in the future, please indicate on the consent sheet if you do not mind us contacting you.

What will I have to do?

Before your first assessment you will be asked to sign a patient consent form which includes the following clause: I understand that I may withdraw from the study at any time without it affecting my ongoing treatment in any way.

All participants will be sent a map and directions to the place of assessment and travel expenses can be reimbursed on production of a receipt for journeys to the assessment venue.

At the beginning of your visit, we will explain the study in full and ask for your consent, bearing in mind that you are free to withdraw at any time.

We will ask you to complete questionnaires that will ask you questions about how the problem affects your activities of daily living.

Prior to the start of the assessment, you may be asked to change into appropriate clothing depending on the joint we want to examine (for example shorts for knee, well fitting vest, sports bra, swimming costume, vest or special apron that leave your chest covered and back bare for shoulder and spine, etc). This process will be conducted with the upmost professionalism and a screened off area is provided for changing. During laboratory sessions, access to the laboratory is limited and a sign is placed on the door advising other staff not to enter whilst the trial is in progress.

You will have a number of very light polystyrene or cork round markers attached to the skin and the locations of the markers will be dependent on the joint type under examination.

You will be asked to perform a range of activities of daily living as appropriate (such as walking, standing, climbing stairs, combing hair, taking hand to mouth). You will be free to stop for a break at any time. The position of the markers on the skin will provide a series of recordings by using cameras that record the position of the markers.

When appropriate to the joint under study, muscle activity, muscle function and joint strength may also be determined during these sessions. This will involve placement of electromyography (EMG) electrodes onto the surface of the skin to record muscle activity during joint movement. The locations of the electrodes will be dependent on the muscle groups under examination. Particularly hairy skin may sometimes need a small patch shaving for the sensors to attach (approximately 2x2cm). In order to determine muscle function electrical muscle stimulation will be used. This involves placing similar electrodes to the EMG on your skin. During certain movements a small stimulus will be applied via the electrode on your skin, this will make your muscle contract more and change your movement slightly. This may cause a strange sensation but will not cause any pain.

Throughout the sessions your joint movement will be recorded using standard audiovisual equipment. The recordings will be used for data verification post processing. We may ask if we can cover any identifying tattoos or birthmarks with a bandage. Your face and any identifying tattoos or birthmarks not covered will be digitally masked from these files so that nobody can identify you from the videos. All data files, including audiovisual files will be stored in encrypted folders on Cardiff University password protected computers. Cardiff University and NHS members of staff who are directly involved with the study will have access to the files.

For studies investigating back pain we will ask you to perform a selection of tasks consisting of everyday functional tasks such as bending, stretching, lifting a cup from a table and finding the best position to sit and stand in. Spinal movements and how muscles work when walking may also be assessed whilst you are walking on a treadmill at different speeds and different inclinations.

We will be looking at which targeted exercise treatments using different instructions are the most beneficial for patients with back pain. These will be compared to treatments currently being used such as general advice and general group exercises.

For studies investigating patient with joint osteoarthritis we will determine the best muscle strengthening programmes including how often and how much exercise a patient needs to get an improvement in their joint pain.

For studies investigating wrist osteoarthritis, we will ask you to have a series of measurements and clinical tests performed on both of your wrists, these will include assessing your grip, range of motion and muscle strength.

For studies investigating shoulder pain, we will ask you to perform a series of actions to measure the movement of your shoulder.

Regular rest and toilet breaks will be provided as often as you need them to assure maximum comfort.

Are there any risks in participating in this trial?

The measurements taken during the trial involve the placement of very light polystyrene or cork round markers onto the skin or EMG electrodes in various places of the body depending on what joint we will be examining. The markers/electrodes are placed with sticky tape which may cause some mild discomfort when it is being removed, similar to removing a small sticking plaster.

Are there any benefits in participating in this trial?

We hope to be able to better understand how joint problems affect the motion of the joint. There is no intended clinical benefit to the participant from taking part in the study. The information we get from this study may help us to provide future patients who have joint disease or injury with improved treatment options.

If the information in Part 1 has interested you and you are considering participation, please read the additional information in Part 2 before making a decision.

Dr Helen Roberts / Dr Andrea Longman
Research Coordinators
Arthritis Research UK Biomechanics and
Bioengineering Centre
Biomedical Sciences Building
Cardiff University
Museum Avenue
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CF10 3AX
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PATIENT INFORMATION SHEET

Assessment of joint function in patients with joint problems using three dimensional motion analysis techniques

Part Two

What if new information becomes available?

Sometimes during the course of a research project, new information becomes available about the investigation. If you decide to withdraw, it will not affect your any care in the NHS. If you decide to continue, you will be asked to sign an updated consent form.

What will happen if I do not want to carry on with the study?

If you withdraw from the study, we will erase all identifiable material, but we will need to use the data collected up to your withdrawal.

What if something goes wrong?

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of this study, the normal National Health Service complaints mechanisms should be available to you.

Will my taking part in this study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential. Any information about you which leaves the Cardiff University or the University Hospital of Wales will have your name and address removed so that you cannot be recognised from it. We may share information (including related medical findings such as radiological images) with external collaborators but all this information will contain no identifiable information about you.

Will my GP be informed of my involvement in the study?

With your permission, we will send a letter to your General Practitioner informing him or her of your involvement in the study.

What will happen to the results of the research study?

The measurements taken will provide information about the movement of your joint. The results of the study will be presented at meetings of orthopaedic surgeons, clinical scientists, physiotherapists and engineers, and if accepted, published in medical and engineering

journals. If interested, a copy of the published article can be made available to you. You will not be identified in any report/publication.

Who is organising and funding the research?

Research staff at the Arthritis Research UK Biomechanics and Bioengineering Centre at Cardiff University and Consultant Orthopaedic Surgeons at the University Hospital of Wales are carrying out the study. The study is part of the Arthritis Research UK Biomechanics and Bioengineering Centre at Cardiff University; it is not funded by commercial sources and runs alongside research in the Cardiff Gait and Motion Analysis Laboratory at Cardiff University School of Engineering and Research Centre for Clinical Kinaesiology at Cardiff University School of Healthcare Studies.

Who has reviewed the study?

This study has been reviewed by the Research Ethics Committee (REC) for Wales.

What if I wish to lodge a complaint?

If you wish to make a minor complaint regarding the way you were approached or treated during the trial, please contact the Arthritis Research UK Biomechanics and Bioengineering Centre Research Coordinator at the contact details below or you can contact the Cardiff University Research Governance Team on 029 208 79277.

Contact for further information

Research Coordinator
Arthritis Research UK Biomechanics and Bioengineering Centre
Cardiff School of Biosciences
Cardiff University
Cardiff
CF10 3AX
Tel: 029 2087 5419
Email: Robertshc@cf.ac.uk or Longmanaj@cf.ac.uk

This completes Part 2. Thank you for reading this information sheet.

If you agree to take part in this study then you will be given a copy of the information sheet and a signed consent form to keep.

Dr Helen Roberts / Dr Andrea Longman
Research Coordinators
Arthritis Research UK Biomechanics and
Bioengineering Centre
Biomedical Sciences Building
Cardiff University
Museum Avenue
Cardiff
CF10 3AX

VOLUNTEER INFORMATION SHEET

Assessment of joint function in healthy subjects using three dimensional motion analysis techniques

Part one

You are being invited to take part in a research study with Cardiff University's Arthritis Research Campaign Biomechanics and Bioengineering Centre. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. One of our team will go through the information sheet with you. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to participate. Part 1 tells you about the purpose of this study and what will happen to you if you take part. Part 2 gives you more detailed information about the conduct of the study.

What is the purpose of this trial?

The aim of the trial is to investigate the function of healthy joints. The data can be helpful when comparing the same measurements in people who have joint problems. Your data can act as the measure of what a healthy joint can achieve. This can be useful when, for example in designing new treatments, improving the design of joint replacements, improving rehabilitation programmes and improving the way that motion is analysed clinically.

Do I have to take part?

It is up to you to whether or not to take part. If you do decide to take part you will be given this information sheet to keep and after you have had enough time to read through it, be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time or without giving a reason. A decision not to take part or to withdraw at any time will not affect the standard of care you receive. Should you decide not to take part, you do not have to provide a reason for this decision.

What will happen to me if I take part?

You have been asked to take part in this as you are volunteering as a healthy subject. It will allow us further insight into the nature of joint function and how healthy people move.

If you wish to take part you will assessed either in the Cardiff University School of Engineering, Human Motion Analysis Laboratory or in the Cardiff University School of Healthcare Studies (SOHCS) Research Centre for Clinical Kinaesiology (RCCK) or in the relevant clinical settings. The number of times we would ask you to attend will be discussed with you when going through this information sheet. The sessions will last a maximum of three hours.

Data will be kept securely for a minimum of 15 years in accordance with good research practice and data protection regulations imposed by Cardiff University in accordance with the Data Protection Act 1998. All data obtained during the study will remain confidential. Access to data will only be available to the investigators attached to the Arthritis Research UK Biomechanics and Bioengineering Centre at Cardiff University.

If new information becomes available, we may invite you to take part in a follow-up study in the future, please indicate on the consent sheet if you do not mind us contacting you.

What will I have to do?

At the beginning of your visit, we will explain the full study to you and ask for your consent, bearing in mind that you are free to withdraw at any time.

Before your first assessment you will be asked to sign a consent form which includes the following clause: I understand that I may withdraw from the study at any time without it affecting any ongoing treatment in any way.

All participants will be sent a map and directions to the place of assessment and travel expenses can be reimbursed on production of a receipt for journeys to the place.

As part of the study appropriate garments will need to be removed and this depends on the joint we want to examine (for example shorts for knee, well fitting vest, sports bra or swimming costume for shoulder and spine, etc). You will be asked to change clothing prior to the start of the assessment, this process will be conducted with the upmost professionalism and a screened off area is provided for changing. During laboratory sessions, access to the laboratory is limited and a sign is placed on the door advising other staff not to enter whilst the trial is in progress.

Firstly you will have a number of very light polystyrene or cork round markers attached to the skin and the locations of the markers will be dependent on the joint type under examination.

You will be asked to perform a range of activities of daily living as appropriate (such as walking, standing, climbing stairs, combing hair, taking hand to mouth). You will be free to stop for a break at any time. The position of the markers on the skin will provide a series of recordings by using cameras that record the position of the markers.

When appropriate to the joint under study, muscle activity, muscle function and joint strength may also be determined during these sessions. This will involve placement of electromyography (EMG) electrodes onto the surface of the skin to record muscle activity during joint movement. The locations

of the electrodes will be dependent on the muscle groups under examination. Particularly hairy skin may sometimes need a small patch shaving for the sensors to attach (approximately 2×2cm). In order to determine muscle function electrical muscle stimulation will be used. This involves placing similar electrodes to the EMG on your skin. During certain movements a small stimulus will be applied via the electrode on your skin, this will make your muscle contract more and change your movement slightly. This may cause a strange sensation but will not cause any pain.

Throughout the sessions your joint movement will be recorded using standard audiovisual equipment. The recordings will be used for data verification post processing. We may ask if we can cover any identifying tattoos or birthmarks with a bandage. Your face and any identifying tattoos or birthmarks not covered will be digitally masked from these files so that nobody can identify you from the videos. All data files, including audiovisual files will be stored in encrypted folders on Cardiff University password protected computers. Cardiff University and NHS members of staff who are directly involved with the study will have access to the files. The audiovisual files will be electronically destroyed up to 15 years from the commencement of the study.

For studies investigating back pain we will ask you to perform a selection of tasks consisting of everyday functional tasks such as bending, stretching, lifting a cup from a table and finding the best position to sit and stand in. Your spinal movements and how muscles work when walking may be assessed whilst walking on a treadmill at different speeds and different inclinations.

We will be looking at which targeted exercise treatments using different instructions are the most beneficial for patients with back pain. These will be compared to treatments currently being used such as general advice and general group exercises.

If you are a healthy volunteer for a study investigating patient with joint osteoarthritis, we are also determining the best muscle strengthening programmes including how often and how much exercise a patient needs to get an improvement in their joint pain.

For studies investigating wrist osteoarthritis, we will ask you to have a series of measurements and clinical tests performed on both of your wrists, these will include assessing your grip, range of motion and muscle strength.

For studies investigating shoulder pain, we will ask you to perform a series of actions to measure the movement of your shoulder.

Regular rest and toilet breaks will be provided as often as you need them to assure maximal comfort.

Are there any risks in participating in this trial?

The measurements taken during the trial involve the placement of very light polystyrene or cork round markers onto the skin or EMG electrodes in various places of the body depending on what joint we will be examining. The markers/electrodes are placed with sticky tape which may cause some mild discomfort when it is being removed, similar to removing a small sticking plaster.

Are there any benefits in participating in this trial?

We hope to be able to better understand how joints move. There is no intended clinical benefit to the participant from taking part in the study. The information we get from this study may help us to provide future patients who have joint disease or injury with improved treatment options.

If the information in Part 1 has interested you and you are considering participation, please read the additional information in Part 2 before making a decision.

Dr Helen Roberts / Dr Andrea Longman
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Bioengineering Centre
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CF10 3AX

VOLUNTEER INFORMATION SHEET

Assessment of joint function in healthy volunteers using three dimensional motion analysis techniques

Part Two

What if new information becomes available?

Sometimes during the course of a research project, new information becomes available about the investigation. If you decide to withdraw, it will not affect your any care in the NHS. If you decide to continue, you will be asked to sign an updated consent form.

What will happen if I do not want to carry on with the study?

If you withdraw from the study, we will erase all identifiable material, but we will need to use the data collected up to your withdrawal.

What if something goes wrong?

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of this study, the normal National Health Service complaints mechanisms should be available to you.

Will my taking part in this study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential. Any information about you which leaves the Cardiff University or the University Hospital of Wales will have your name and address removed so that you cannot be recognised from it. We may share information with external collaborators but all this information will contain no identifiable information about you.

Will my GP be informed of my involvement in the study?

With your permission, we will send a letter to your General Practitioner informing him or her of your involvement in the study.

What will happen to the results of the research study?

The measurements taken will provide information about the movement of your joint. The results of the study will be presented at meetings of orthopaedic surgeons, clinical scientists, physiotherapists and engineers, and if accepted, published in medical and engineering journals. If interested, a copy of the published article can be made available to you. You will not be identified in any report/publication.

Who is organising and funding the research?

Research staff at the Arthritis Research UK Biomechanics and Bioengineering Centre at Cardiff University and Consultant Orthopaedic Surgeons at the University Hospital of Wales are carrying out the study. The study is part of the Arthritis Research UK Biomechanics and Bioengineering Centre at Cardiff University; it is not funded by commercial sources and runs alongside research in the Cardiff Gait and Motion Analysis Laboratory at Cardiff University School of Engineering and Research Centre for Clinical Kinaesiology at Cardiff University School of Healthcare Studies.

Who has reviewed the study?

This study has been reviewed by the Research Ethics Committee (REC) for Wales.

What if I wish to lodge a complaint?

If you wish to make a minor complaint regarding the way you were approached or treated during the trial, please contact the Arthritis Research UK Biomechanics and Bioengineering Centre Research Coordinator at the contact details below or you can contact the Cardiff University Research Governance Team on 029 208 79277.

Contact for further information

Research Coordinator
Arthritis Research UK Biomechanics and Bioengineering Centre
Cardiff School of Biosciences
Cardiff University
Cardiff
CF10 3AX
Tel: 029 2087 5419
Email: Robertshc@cf.ac.uk or Longmanaj@cf.ac.uk

This completes Part 2. Thank you for reading this information sheet.

If you agree to take part in this study you will be given a copy of the information sheet and a signed consent form to keep.

Dr Helen Roberts / Dr Andrea Longman
Research Coordinators
Arthritis Research UK Biomechanics and
Bioengineering Centre
Biomedical Sciences Building
Cardiff University
Museum Avenue
Cardiff
CF10 3AX
Tel: 029 20875419

CONSENT FORM

Assessment of joint function in patients with joint problems using three dimensional motion analysis techniques

Study Number

Patient Identification Number for this trial:

You DO NOT have to sign this document. Please DO NOT sign this document unless you fully understand it. If there is ANYTHING which you do not understand please do not hesitate to ask for a full explanation.

To confirm agreement with each of the statements below, please initial each box:

1. I confirm that I have read and understand the information sheet dated 30/06/2012 (Version 6) for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation in the study is voluntary and that I am free to withdraw at any time, without giving any reason, and without my medical care or legal rights being affected. ☐

3. You may contact me in the future to take part in other research projects or surveys. ☐

4. I agree to you accessing appropriate related medical information (such as radiological images) for the purposes of this study. ☐

5. I agree for you to share anonymised information obtained in point 4 with external collaborators. ☐

6. I agree to my hospital number being used to track my data on your secure system. ☐

7. I agree to my GP being informed of my participation in the study. ☐

8. I agree to take part in the above study. ☐

Name of Patient: _____

(Please print)

Signature: _____ Date: _____

I confirm that I have fully explained the experimental protocol and purpose of the study

Name of Researcher: _____

Signature: _____ Date: _____

Name of person taking consent: _____

(If different from researcher)

Signature: _____ Date: _____

1 copy for the patient; 1 copy for the researcher

Dr Helen Roberts / Dr Andrea Longman
Research Coordinators
Arthritis Research UK Biomechanics and
Bioengineering Centre
Biomedical Sciences Building
Cardiff University
Museum Avenue
Cardiff
CF10 3AX
Tel: 029 20875419

VOLUNTEER CONSENT FORM

Assessment of joint function in healthy volunteers using three dimensional motion analysis techniques

Study Number:

Volunteer Identification Number for this trial:

You DO NOT have to sign this document. Please DO NOT sign this document unless you fully understand it. If there is ANYTHING which you do not understand please do not hesitate to ask for a full explanation.

To confirm agreement with each of the statements below, please initial the box:

1. I confirm that I have read and understand the information sheet dated 30/06/2012 (Version 6) for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation in the study is voluntary and that I am free to withdraw at any without giving any reason, and without my medical care or legal rights being affected. ☐

3. You may contact me in the future to take part in other research projects or surveys. ☐

4. I agree for you to share anonymised information with external collaborators. ☐

5. I agree to my GP being informed of my participation in the study. ☐

6. I agree to my hospital number being used to track my tissue on your secure system ☐

67 I agree to take part in the above study. ☐

Name of Patient: _____

Signature: _____ Date: _____

I confirm that I have fully explained the experimental protocol and purpose of the study

Name of Researcher: _____

Signature: _____ Date: _____

Name of person taking consent: _____
(If different from researcher)

Signature: _____ Date: _____

1 copy for the patient; 1 copy for the researcher

Patient recruitment letter

Dear

Re: Back pain research being undertaken in the Arthritis Research UK Biomechanics and Bioengineering Centre, Cardiff University.

You are being contacted as you are currently awaiting physiotherapy treatment for your back pain at Cardiff and Vale University Health Board. We have been asked by Rebecca Hemming (PhD researcher/physiotherapist) to see if you would be interested in participating in a research project on back pain. This study will look at differences in how people with and without back pain move during normal daily activities. There may also be an opportunity to participate in a further study evaluating targeted treatment for back pain.

You have therefore been invited to participate in the research study to assess your movements during a range of daily activities such as walking, reaching, bending and sitting. The information sheets for the study are enclosed.

If you are interested in participating in the study and are happy to be contacted by a member of the research team to see if you would be eligible **please complete the 'Permission to Contact Form' enclosed and return in the stamped addressed envelope provided (ideally within 2 weeks).**

Alternatively, you can **contact the research team directly on 07531711508** or email HemmingRL@cf.ac.uk for further information about the study. You will only be contacted if you return the form or contact the research team directly

Yours sincerely

Adrian Broad
Strategic Lead Outpatient Physiotherapy
University Hospital of Wales, Cardiff & Vale University Health Board.

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Arthritis Research UK
Providing answers today and tomorrow

APPENDIX V

Data Collection

Red Flags

Standardised Data Collection Instructions

Patient Exercise Sheet

Red Flags

Summary of red flags (clinical signs of serious underlying pathology) as outlined by Waddell (2004)

Condition	**Red Flag** (Clinical signs of serious underlying pathology)
Serious Spinal Pathology	Presentation age <20 or >55 (age of onset) Violent trauma Constant, progressive, non-mechanical pain Thoracic pain Previous history of carcinoma, systemic steroid use, drug abuse, HIV Systemically unwell (weight loss) Persisting severe restriction of lumbar flexion Widespread neurology (pins and needles, weakness) Structural deformity Vertebral collapse or bone destruction on X-ray
Cauda Equina Syndrome	Difficulty with micturition Loss of anal sphincter tone, faecal incontinence Saddle anaesthesia around anus, perineus, genitalia Widespread (>1 nerve root) progressive motor weakness in the lower limbs, gait disturbance
Systemic Inflammatory Disorder	Gradual onset before 40 years of age Marked morning joint stiffness Persisting limitation of spinal movement in all directions Peripheral joint involvement (small hand and foot joints) Iritis, skin rash, psoriasis, colitis Family history

Standardised data collection instructions (for NISCHR Research Officers)

These are guidelines for the verbal instructions of patient tasks, which were followed by the NISCHR Research Officers assisting with data collection

Verbal Instructions

Usual Standing Posture*: Stand feet shoulder width apart, arms hanging freely. Look straight ahead. Stand in your usual standing position*.

Full Flexion (and return) in Standing*: Stand feet shoulder-width apart, knees straight and arms hanging freely, bend forward as far as possible, like touching your toes, pause for a couple of seconds at the end, and then rise to an upright posture. Keep your knees straight all the times and feet stationary.*

Full Extension (and return) in Standing*: Stand feet shoulder-width apart, knees straight and arms hanging freely, bend forward as far as possible, like touching your toes, pause for a couple of seconds at the end, and then rise to an upright posture. Keep your knees straight all the times and feet stationary.*

Usual Sitting Posture: *Sit on the plinth as you would usually (during unsupported sitting)*

Sit to stand (STS)/ Stand-to sit: *Sit on the plinth as you would usually. When instructed, stand up as you would usually. Stand for 2-3 seconds. Return to sitting as you would usually.*

Box Rotation: *Stand so your feet are almost at the front of the square on the floor. Keep your feet stationary throughout. When instructed pick up the box and move it to the right and place it over the marked line. Ensure that the box is still facing the same way at the end of the trial. Return to your usual standing position.*

Reaching: *Hold the jar in your right hand. Stand in your usual standing position keeping your feet stationary throughout (heels on the floor). When instructed, place the jar onto the shelf. Do not let go of the jar. Hold at the end for 2 seconds and return to your usual standing position.*

Step up/ down: *Stand facing the step. When instructed, step up onto the step ait for 2 seconds then step down off the front of the step and remain standing for 2 seconds. You may use whichever leg feels*

most comfortable to step up and step down. Please ensure the same leg leads and steps down on each trial.

Picking up a pencil: *Stand in your usual standing position. Pick up the pen off the floor in front of you and return to standing. Please do not move your feet from their starting position. You may move in whichever way feels natural for you.*

What to do if your back is sore

1. <u>Gentle mobilising exercises</u>

   - knee rolling

   -

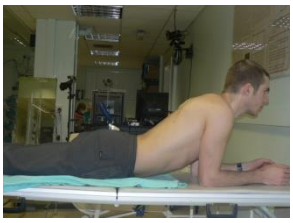
   - knees to chest with help of your arms

   -

   -

   - lying on your front propped up on your elbows

   -

   -

   - pelvic tilts (lying on your back, knees bent, flatten your back)

For further information or if you have any questions please call:

Becci Hemming
07531711508
02920 74 8156

2. <u>Heat</u>

   - hot water bottle
   - hot shower, avoid hot bath

3. <u>Daily activities</u>

   - keep moving
   - avoid prolonged slouched sitting, get up and walk about, stretch your back
   - go for a gentle walk

APPENDIX VI

Questionnaires

Visual Analogue Scale Questionnaire

International Physical Activity Monitoring Questionnaire (Short Form)

Tampa Scale of Kinesiophobia

STarT Back Tool

Oswestry Disability Questionnaire

Distress and Risk Assessment Method

Visual Analog Scale Questionnaire

Instructions: **Put a mark on the line at the point that best represents your pain**

1 – What is your pain RIGHT NOW?

No pain ——————————————————— **Worst possible pain**

0 1 2 3 4 5 6 7 8 9 10

2 – What is your TYPICAL or AVERAGE pain?

No pain ——————————————————— **Worst possible pain**

0 1 2 3 4 5 6 7 8 9 10

3 – What is your pain level AT ITS BEST (How close to "0" does your pain get at its best)?

No pain ——————————————————— **Worst possible pain**

0 1 2 3 4 5 6 7 8 9 10

4 – What is your pain level AT ITS WORST (How close to "10" does your pain get at its worst)?

No pain ——————————————————— **Worst possible pain**

0 1 2 3 4 5 6 7 8 9 10

OTHER COMMENTS:

_____

_____

_____

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.

At A Glance
IPAQ Scoring Protocol (Short Forms)

Continuous Score

Expressed as MET-min per week: MET level x minutes of activity/day x days per week

Sample Calculation

MET levels	**MET-minutes/week for 30 min/day, 5 days**
Walking = 3.3 METs	3.3*30*5 = 495 MET-minutes/week
Moderate Intensity = 4.0 METs	4.0*30*5 = 600 MET-minutes/week
Vigorous Intensity = 8.0 METs	8.0*30*5 = 1,200 MET-minutes/week
	TOTAL = 2,295 MET-minutes/week

Total MET-minutes/week = Walk (METs*min*days) + Mod (METs*min*days) + Vig (METs*min*days)

Categorical Score- three levels of physical activity are proposed

1. **Low**

   - No activity is reported **OR**
   - Some activity is reported but not enough to meet Categories 2 or 3.

2. **Moderate**

   Either of the following 3 criteria
   - 3 or more days of vigorous activity of at least 20 minutes per day **OR**
   - 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day **OR**
   - 5 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of at least 600 MET-minutes/week.

3. **High**

   Any one of the following 2 criteria
   - Vigorous-intensity activity on at least 3 days and accumulating at least 1500 MET-minutes/week **OR**
   - 7 or more days of any combination of walking, moderate- or vigorous-intensity activities accumulating at least 3000 MET-minutes/week

Please review the full document "Guidelines for the data processing and analysis of the International Physical Activity Questionnaire" for more detailed description of IPAQ analysis and recommendations for data cleaning and processing [www.ipaq.ki.se].

Tampa Scale for Kinesiophobia

(Miller , Kori and Todd 1991)

1 = strongly disagree
2 = disagree
3 = agree
4 = strongly agree

1. I'm afraid that I might injury myself if I exercise	1	2	3	4
2. If I were to try to overcome it, my pain would increase	1	2	3	4
3. My body is telling me I have something dangerously wrong	1	2	3	4
4. My pain would probably be relieved if I were to exercise	1	2	3	4
5. People aren't taking my medical condition seriously enough	1	2	3	4
6. My accident has put my body at risk for the rest of my life	1	2	3	4
7. Pain always means I have injured my body	1	2	3	4
8. Just because something aggravates my pain does not mean it is dangerous	1	2	3	4
9. I am afraid that I might injure myself accidentally	1	2	3	4
10. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	1	2	3	4
11. I wouldn't have this much pain if there weren't something potentially dangerous going on in my body	1	2	3	4
12. Although my condition is painful, I would be better off if I were physically active	1	2	3	4
13. Pain lets me know when to stop exercising so that I don't injure myself	1	2	3	4
14. It's really not safe for a person with a condition like mine to be physically active	1	2	3	4
15. I can't do all the things normal people do because it's too easy for me to get injured	1	2	3	4
16. Even though something is causing me a lot of pain, I don't think it's actually dangerous	1	2	3	4
17. No one should have to exercise when he/she is in pain	1	2	3	4

Reprinted from:
Pain, Fear of movement/(re) injury in chronic low back pain and its relation to behavioral performance, 62, Vlaeyen, J., Kole-Snijders A., Boeren R., van Eek H., 371.

Scoring Information
Tampa Scale for Kinesiophobia
(Miller et al 1991)

A total score is calculated after inversion of the individual scores of items 4, 8, 12 and 16.

STarT Back Screening Tool

Patient name: _____ Date: _____

Thinking about the **last 2 weeks** tick your response to the following questions:

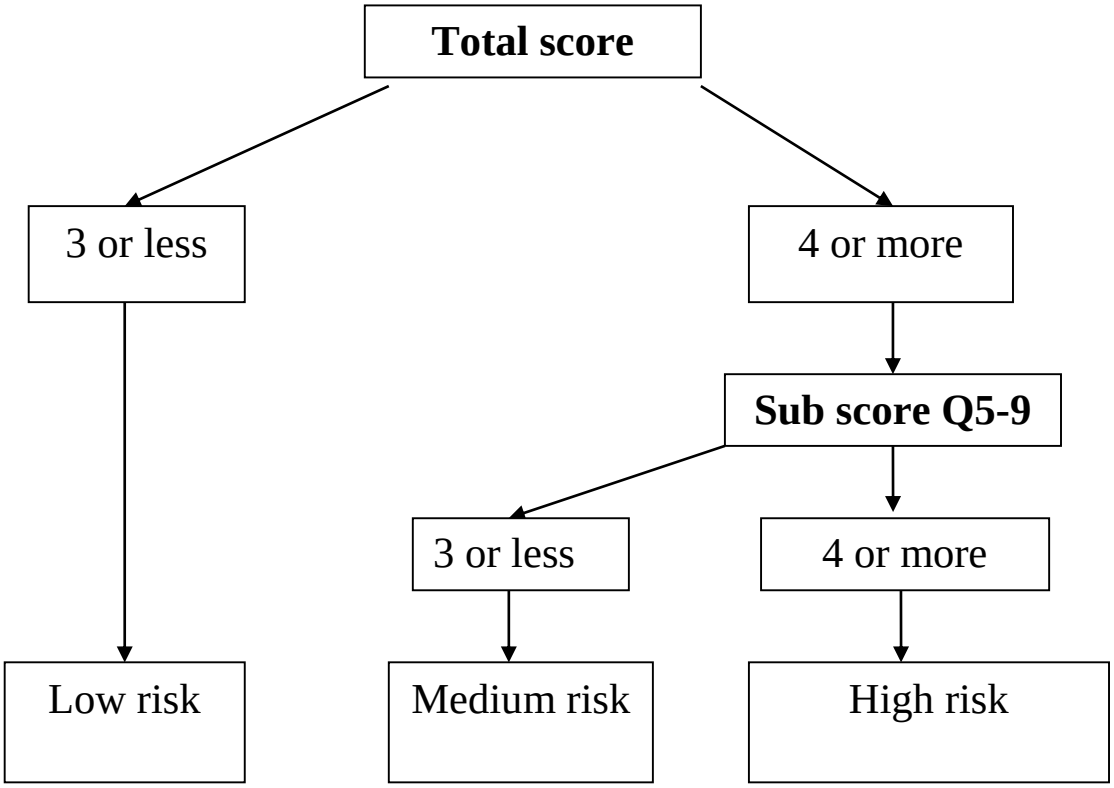
		Disagree 0	**Agree** 1
1	My back pain has **spread down my leg(s)** in the last 2 weeks	☐	☐
2	I have had pain in the **shoulder** or **neck** at some time in the last 2 weeks	☐	☐
3	I have only **walked short distances** because of my back pain	☐	☐
4	In the last 2 weeks, I have **dressed more slowly** than usual because of back pain	☐	☐
5	It's not really safe for a person with a condition like mine to be physically active	☐	☐
6	**Worrying thoughts** have been going through my mind a lot of the time	☐	☐
7	I feel that **my back pain is terrible** and **it's never going to get any better**	☐	☐
8	In general I have **not enjoyed** all the things I used to enjoy	☐	☐

9. Overall, how **bothersome** has your back pain been in the **last 2 weeks**?

Not at all	Slightly	Moderately	Very much	Extremely
☐	☐	☐	☐	☐
0	0	0	1	1

Total score (all 9): _____ **Sub Score (Q5-9):_____**

STarT Back Tool Scoring System



Oswestry Low Back Pain Disability Questionnaire

Instructions

This questionnaire has been designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please answer by checking ONE box in each section for the statement which best applies to you. We realise you may consider that two or more statements in any one section apply but please just shade out the spot that indicates the statement which most clearly describes your problem.

Section 1 – Pain intensity

- ☐ I have no pain at the moment
- ☐ The pain is very mild at the moment
- ☐ The pain is moderate at the moment
- ☐ The pain is fairly severe at the moment
- ☐ The pain is very severe at the moment
- ☐ The pain is the worst imaginable at the moment

Section 2 – Personal care (washing, dressing etc)

- ☐ I can look after myself normally without causing extra pain
- ☐ I can look after myself normally but it causes extra pain
- ☐ It is painful to look after myself and I am slow and careful
- ☐ I need some help but manage most of my personal care
- ☐ I need help every day in most aspects of self-care
- ☐ I do not get dressed, I wash with difficulty and stay in bed

Section 3 – Lifting

- ☐ I can lift heavy weights without extra pain
- ☐ I can lift heavy weights but it gives extra pain
- ☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently placed eg. on a table
- ☐ Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned
- ☐ I can lift very light weights
- ☐ I cannot lift or carry anything at all

Section 4 – Walking*

- ☐ Pain does not prevent me walking any distance
- ☐ Pain prevents me from walking more than 1 mile
- ☐ Pain prevents me from walking more than 1/2 mile
- ☐ Pain prevents me from walking more than 100 yards
- ☐ I can only walk using a stick or crutches
- ☐ I am in bed most of the time

Section 5 – Sitting

- ☐ I can sit in any chair as long as I like
- ☐ I can only sit in my favourite chair as long as I like
- ☐ Pain prevents me sitting more than one hour
- ☐ Pain prevents me from sitting more than 30 minutes
- ☐ Pain prevents me from sitting more than 10 minutes
- ☐ Pain prevents me from sitting at all

Section 6 – Standing

- ☐ I can stand as long as I want without extra pain
- ☐ I can stand as long as I want but it gives me extra pain
- ☐ Pain prevents me from standing for more than 1 hour
- ☐ Pain prevents me from standing for more than 30 minutes
- ☐ Pain prevents me from standing for more than 10 minutes
- ☐ Pain prevents me from standing at all

Section 7 – Sleeping

- ☐ My sleep is never disturbed by pain
- ☐ My sleep is occasionally disturbed by pain
- ☐ Because of pain I have less than 6 hours sleep
- ☐ Because of pain I have less than 4 hours sleep
- ☐ Because of pain I have less than 2 hours sleep
- ☐ Pain prevents me from sleeping at all

Section 8 – Sex life (if applicable)

- ☐ My sex life is normal and causes no extra pain
- ☐ My sex life is normal but causes some extra pain
- ☐ My sex life is nearly normal but is very painful
- ☐ My sex life is severely restricted by pain
- ☐ My sex life is nearly absent because of pain
- ☐ Pain prevents any sex life at all

Section 9 – Social life

- ☐ My social life is normal and gives me no extra pain
- ☐ My social life is normal but increases the degree of pain
- ☐ Pain has no significant effect on my social life apart from limiting my more energetic interests eg, sport
- ☐ Pain has restricted my social life and I do not go out as often
- ☐ Pain has restricted my social life to my home
- ☐ I have no social life because of pain

Section 10 – Travelling

- ☐ I can travel anywhere without pain
- ☐ I can travel anywhere but it gives me extra pain
- ☐ Pain is bad but I manage journeys over two hours
- ☐ Pain restricts me to journeys of less than one hour
- ☐ Pain restricts me to short necessary journeys under 30 minutes
- ☐ Pain prevents me from travelling except to receive treatment

References

1. Fairbank JC, Pynsent PB. The Oswestry Disability Index. Spine 2000 Nov 15;25(22):2940-52; discussion 52.

Oswestry Low Back Pain Disability Questionnaire

Sources: Fairbank JCT & Pynsent, PB (2000) The Oswestry Disability Index. *Spine*, 25(22):2940-2953.

Davidson M & Keating J (2001) A comparison of five low back disability questionnaires: reliability and responsiveness. *Physical Therapy* 2002;82:8-24.

The Oswestry Disability Index (also known as the Oswestry Low Back Pain Disability Questionnaire) is an extremely important tool that researchers and disability evaluators use to measure a patient's permanent functional disability. The test is considered the 'gold standard' of low back functional outcome tools [1].

Scoring instructions

For each section the total possible score is 5: if the first statement is marked the section score = 0; if the last statement is marked, it = 5. If all 10 sections are completed the score is calculated as follows:

Example: 16 (total scored)

50 (total possible score) x 100 = 32%

If one section is missed or not applicable the score is calculated:

16 (total scored)

45 (total possible score) x 100 = 35.5%

Minimum detectable change (90% confidence): 10% points (change of less than this may be attributable to error in the measurement)

Interpretation of scores

0% to 20%: minimal disability:	The patient can cope with most living activities. Usually no treatment is indicated apart from advice on lifting sitting and exercise.
21%-40%: moderate disability:	The patient experiences more pain and difficulty with sitting, lifting and standing. Travel and social life are more difficult and they may be disabled from work. Personal care, sexual activity and sleeping are not grossly affected and the patient can usually be managed by conservative means.
41%-60%: severe disability:	Pain remains the main problem in this group but activities of daily living are affected. These patients require a detailed investigation.
61%-80%: crippled:	Back pain impinges on all aspects of the patient's life. Positive intervention is required.
81%-100%:	These patients are either bed-bound or exaggerating their symptoms.

Distress and Risk Assessment Method (DRAM)

Modified Somatic Perceptions Questionnaire

Main C, Wood P, Hillis S, et al (1992)

Please describe how you have felt during the PAST WEEK by marking a check mark (√) in the appropriate box. Please answer all questions. Do not think too long before answering.

	Not at all	A little, slightly	A great deal, quite a bit	Extremely, could not have been worse
Heart rate increase				
Feeling hot all over				
Sweating all over				
Sweating in a particular part of the body				
Pulse in neck				
Pounding in head				
Dizziness				
Blurring of vision				
Feeling faint				
Everything appearing unreal				
Nausea				
Butterflies in stomach				
Pain or ache in stomach				
Stomach churning				
Desire to pass water				
Mouth becoming dry				
Difficulty swallowing				
Muscles in neck aching				
Legs feeling weak				
Muscles twitching or jumping				
Tense feeling across forehead				
Tense feeling in jaw muscles				

Source: Main C, Wood P, Hillis S, et al. The Distress and Risk Assessment Method. A simple patient classification to identify distress and evaluate the risk of poor outcome. *Spine* 1992; 17: 42-52.

Modified Somatic Perceptions Questionnaire: Scoring

Please describe how you have felt during the PAST WEEK by marking a check mark (√) in the appropriate box. Please answer all questions. Do not think too long before answering.				
	Not at all	A little, slightly	A great deal, quite a bit	Extremely, could not have been worse
Heart rate increase				
Feeling hot all over	0	1	2	3
Sweating all over	0	1	2	3
Sweating in a particular part of the body				
Pulse in neck				
Pounding in head				
Dizziness	0	1	2	3
Blurring of vision	0	1	2	3
Feeling faint	0	1	2	3
Everything appearing unreal				
Nausea	0	1	2	3
Butterflies in stomach				
Pain or ache in stomach	0	1	2	3
Stomach churning	0	1	2	3
Desire to pass water				
Mouth becoming dry	0	1	2	3
Difficulty swallowing				
Muscles in neck aching	0	1	2	3
Legs feeling weak	0	1	2	3
Muscles twitching or jumping	0	1	2	3
Tense feeling across forehead	0	1	2	3
Tense feeling in jaw muscles				

Source: Main C, Wood P, Hollis S, Spanswick, C, Waddell, G (1992) The Distress and Risk Assessment Method. A simple patient classification to identify distress and evaluate the risk of poor outcome. Spine 17: 42-52.

Modified Zung Depression Index

Main C, Wood P, Hillis S, et al (1992)

Please indicate for each of these questions which answer best describes how you have been feeling recently.

	Rarely or none of the time (less than 1 day per week)	Some or little of the time (1-2 days per week)	À moderate amount of time (3-4days per week)	Most of the time (5-7 days per week
1. I feel downhearted and sad				
2. Morning is when I feel best				
3. I have crying spells or feel like it				
4. I have trouble getting to sleep at night				
5. I feel that nobody cares				
6. I eat as much as I used to				
7. I still enjoy sex				
8. I notice I am losing weight				
9. I have trouble with constipation				
10. My heart beats faster than usual				
11. I get tired for no reason				
12. My mind is as clear as it used to be				
13. I tend to wake up too early				
14. I find it easy to do the things I used to				
15. I am restless and can't keep still				
16. I feel hopeful about the future				
17. I am more irritable than usual				
18. I find it easy to make a decision				
19. I feel quite guilty				
20. I feel that I am useful and needed				
21. My life is pretty full				
22. I feel that others would be better off I were dead				
23. I am still able to enjoy the things I used to				

Source: Main C, Wood P, Hillis S, et al. The Distress and Risk Assessment Method. A simple patient classification to identify distress and evaluate the risk of poor outcome. *Spine* 1992; 17: 42-52.

Modified Zung Depression Index: Scoring

Please indicate for each of these questions which answer best describes how you have been feeling recently.

	Rarely or none of the time (less than 1 day per week)	Some or little of the time (1-2 days per week)	À moderate amount of time (3-4days per week)	Most of the time (5-7 days per week
1. I feel downhearted and sad	0	1	2	3
2. Morning is when I feel best	3	2	1	0
3. I have crying spells or feel like it	0	1	2	3
4. I have trouble getting to sleep at night	0	1	2	3
5. I feel that nobody cares	0	1	2	3
6. I eat as much as I used to	3	2	1	0
7. I still enjoy sex	3	2	1	0
8. I notice I am losing weight	0	1	2	3
9. I have trouble with constipation	0	1	2	3
10. My heart beats faster than usual	0	1	2	3
11. I get tired for no reason	0	1	2	3
12. My mind is as clear as it used to be	3	2	1	0
13. I tend to wake up too early	0	1	2	3
14. I find it easy to do the things I used to	3	2	1	0
15. I am restless and can't keep still	0	1	2	3
16. I feel hopeful about the future	3	2	1	0
17. I am more irritable than usual	0	1	2	3
18. I find it easy to make a decision	3	2	1	0
19. I feel quite guilty	0	1	2	3
20. I feel that I am useful and needed	3	2	1	0
21. My life is pretty full	3	2	1	0
22. I feel that others would be better off I were dead	0	1	2	3
23. I am still able to enjoy the things I used to	3	2	1	0

Source: Main C, Wood P, Hollis S, Spanswick, C, Waddell, G (1992) The Distress and Risk Assessment Method. A simple patient classification to identify distress and evaluate the risk of poor outcome. Spine 17: 42-52.

APPENDIX VII

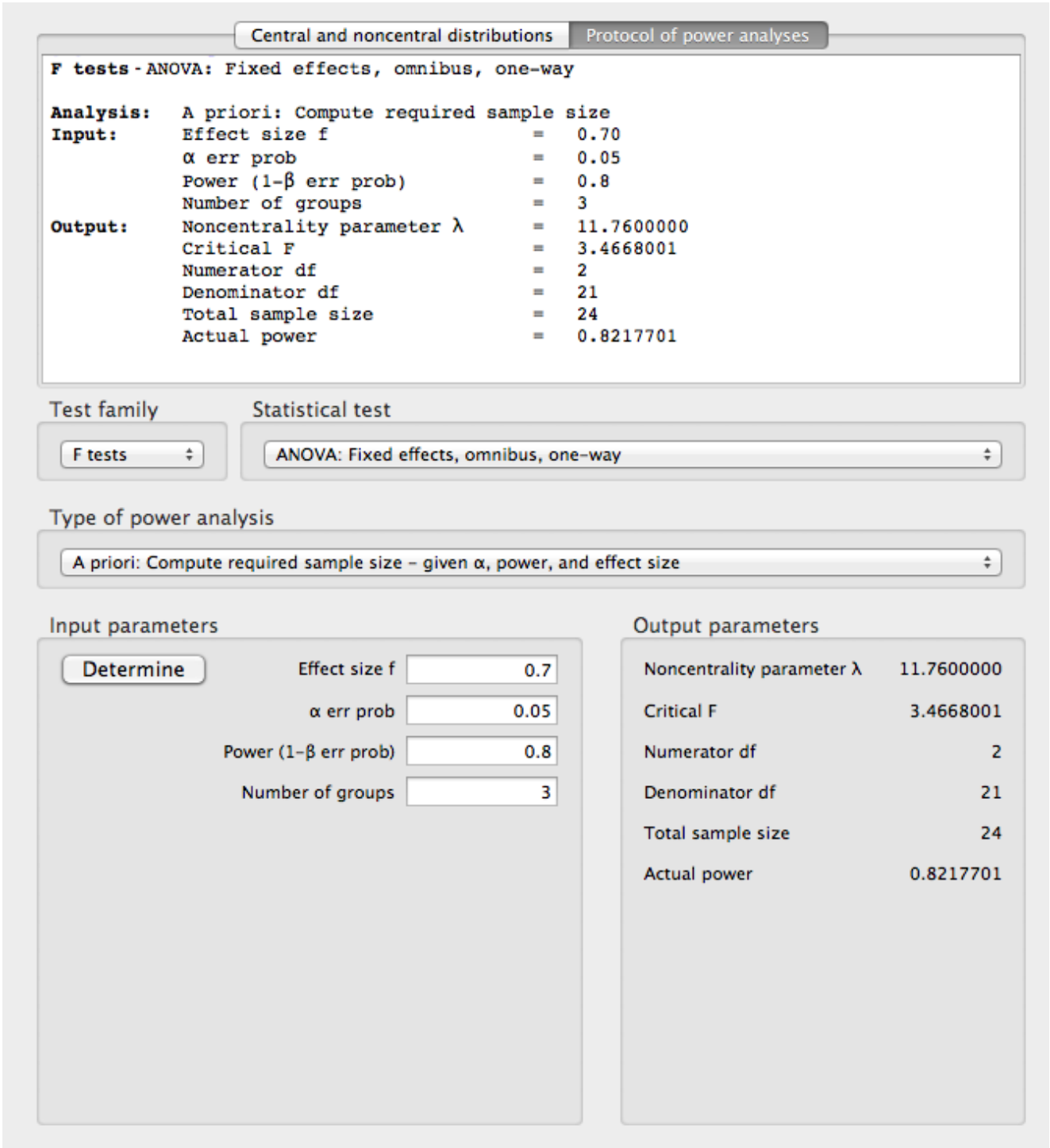
Data Considerations

Power Calculation

Bonferroni Adjustment

Power Calculation

Output of G*Power Software – Sample size calculation based on Dankaerts et al, 2006c (Lower lumbar sagittal spinal angles in sitting for active extension pattern, flexion pattern and healthy control groups)



Bonferroni Adjustment

The following text is a direct quote from the IBM SPSS help procedures to outline how Bonferroni testing is performed using SPSS.
Source: http://www-01.ibm.com/support/docview.wss?uid=swg21476685

The calculation of Bonferroni-adjusted p-values

Technote (troubleshooting)

Problem (Abstract)
How does SPSS calculate the Bonferroni-corrected p-values for pairwise comparisons?

Resolving the problem
SPSS offers Bonferroni-adjusted significance tests for pairwise comparisons. This adjustment is available as an option for post hoc tests and for the estimated marginal means feature.

Statistical textbooks often present Bonferroni adjustment (or correction) in the following terms. First, divide the desired alpha-level by the number of comparisons. Second, use the number so calculated as the p-value for determining significance. So, for example, with alpha set at .05, and three comparisons, the LSD p-value required for significance would be .05/3 = .0167.

SPSS and some other major packages employ a mathematically equivalent adjustment. Here's how it works. Take the observed (uncorrected) p-value and multiply it by the number of comparisons made. What does this mean in the context of the previous example, in which alpha was set at .05 and there were three pairwise comparisons? It's very simple. Suppose the LSD p-value for a pairwise comparison is .016. This is an unadjusted p-value. To obtain the corrected p-value, we simply multiply the uncorrected p-value of .016 by 3, which equals .048. Since this value is less than .05, we would conclude that the difference was significant.

Finally, it's important to understand what happens when the product of the LSD p-value and the number of comparisons exceeds 1. In such cases, the Bonferroni-corrected p-value

reported by SPSS will be 1.000. The reason for this is that probabilities cannot exceed 1. With respect to the previous example, this means that if an LSD p-value for one of the contrasts were .500, the Bonferroni-adjusted p-value reported would be 1.000 and not 1.500, which is the product of .5 multiplied by 3.

APPENDIX VIII

Normality and Homogeneity of Variance

Demographics

Kinematics – Posture and Range of Movement

Kinematics - Tasks

DEMOGRAPHICS

Tests of Normality (observed values)

	Classification Group	Shapiro-Wilk			
		Statistic	Statistic	df	Sig.
Age	AEP	.163	.947	23	.252
	FP	.112	.937	27	.104
	Control	.117	.973	28	.670
Height (cm)	AEP	.120	.964	23	.560
	FP	.089	.966	27	.507
	Control	.093	.979	28	.830
Weight (kg)	AEP	.140	.916	23	.055
	FP	.088	.991	27	.997
	Control	.226	.840	28	.001
BMI	AEP	.165	.903	23	.029
	FP	.141	.967	27	.521
	Control	.214	.848	28	.001

Key: AEP = Active Extension Pattern; FP = Flexion Pattern

Tests of Homogeneity of Variance (observed values)

		Levene Statistic	df1	df2	Sig.
Age	Based on Mean	.271	2	75	.764
	Based on Median	.259	2	75	.772
Height (cm)	Based on Mean	1.259	2	75	.290
	Based on Median	1.194	2	75	.309
Weight (kg)	Based on Mean	1.195	2	75	.308
	Based on Median	.832	2	75	.439
BMI	Based on Mean	2.672	2	75	.076
	Based on Median	1.657	2	75	.198

KINEMATICS – Postures and Range of Movement

Tests of Normality (observed values)

	Classification Group	Shapiro-Wilk		
		Statistic	df	Sig.
Usual Stand TotLx	AEP	.938	12	.477
	FP	.943	10	.587
	Control	.958	11	.743
Usual Stand LLx	AEP	.955	12	.718
	FP	.931	10	.457
	Control	.894	11	.156
Usual Stand ULx	AEP	.953	12	.684
	FP	.901	10	.227
	Control	.981	11	.970
Usual Stand TotTx	AEP	.949	12	.618
	FP	.912	10	.293
	Control	.921	11	.330
Usual Stand LTx	AEP	.867	12	.059
	FP	.962	10	.812
	Control	.969	11	.876
Usual Stand UTx	AEP	.893	12	.129
	FP	.951	10	.680
	Control	.923	11	.343
Usual Sitting TotLx	AEP	.966	12	.861
	FP	.891	10	.175
	Control	.842	11	.033
Usual Sitting LLx	AEP	.982	12	.991
	FP	.879	10	.126
	Control	.863	11	.062
Usual Sitting ULx	AEP	.961	12	.798
	FP	.803	10	.016
	Control	.965	11	.835
Usual Sitting TotTx	AEP	.959	12	.771
	FP	.910	10	.283
	Control	.821	11	.018
Usual Sitting LTx	AEP	.939	12	.489

	FP	.941	10	.560
	Control	.927	11	.382
	AEP	.942	12	.523
Usual Sitting UTx	FP	.869	10	.098
	Control	.922	11	.335
	AEP	.939	12	.491
Flexion TotLx	FP	.851	10	.060
	Control	.947	11	.605
	AEP	.901	12	.164
Flexion LLx	FP	.911	10	.288
	Control	.922	11	.340
	AEP	.767	12	.004
Flexion ULx	FP	.956	10	.737
	Control	.901	11	.190
	AEP	.946	12	.575
Flexion TotTx	FP	.938	10	.535
	Control	.891	11	.144
	AEP	.960	12	.779
Flexion LTx	FP	.937	10	.517
	Control	.931	11	.422
	AEP	.916	12	.258
Flexion UTx	FP	.962	10	.812
	Control	.853	11	.047
	AEP	.910	12	.212
Extension TotLx	FP	.919	10	.349
	Control	.947	11	.606
	AEP	.940	12	.496
Extension LLx	FP	.932	10	.464
	Control	.943	11	.561
	AEP	.888	12	.112
Extension ULx	FP	.955	10	.729
	Control	.928	11	.389
	AEP	.942	12	.525
Extension TotTx	FP	.879	10	.127
	Control	.915	11	.281
Extension LTx	AEP	.937	12	.461

	FP	.984	10	.985
	Control	.979	11	.959
	AEP	.979	12	.978
Extension UTx	FP	.955	10	.730
	Control	.961	11	.780

Key: TotLx = total lumbar spine angle; LLx = lower lumbar spine angle; ULx = upper lumbar spine angle; TotTx = total thoracic spine angle; LTx = lower thoracic spine angle; UTx = upper thoracic spine angle; AEP = Active Extension Pattern; FP = Flexion Pattern

Tests of Homogeneity of Variance (observed values)

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Usual Stand TotLx	1.355	2	75	.264
Usual Stand LLx	.527	2	75	.592
Usual Stand ULx	.622	2	75	.540
Usual Stand TotTx	3.558	2	75	.033
Usual Stand LTx	.313	2	75	.732
Usual Stand UTx	2.817	2	75	.066
Usual Sitting TotLx	1.869	2	75	.161
Usual Sitting LLx	1.167	2	75	.317
Usual Sitting ULx	.270	2	75	.764
Usual Sitting TotTx	.794	2	75	.456
Usual Sitting LTx	1.946	2	75	.150
Usual Sitting UTx	1.311	2	75	.276
Flexion TotLx	.250	2	75	.779
Flexion LLx	2.600	2	31	.090
Flexion ULx	1.432	2	47	.249
Flexion TotTx	2.409	2	75	.097
Flexion LTx	1.066	2	75	.349
Flexion UTx	2.747	2	75	.071
Extension TotLx	4.193	2	70	.019
Extension LLx	.064	2	68	.938
Extension ULx	.281	2	73	.756
Extension TotTx	3.102	2	75	.051
Extension LTx	3.435	2	75	.037
Extension UTx	1.564	2	75	.216

Key: TotLx = total lumbar spine angle; LLx = lower lumbar spine angle; ULx = upper lumbar spine angle; TotTx = total thoracic spine angle; LTx = lower thoracic spine angle; UTx = upper thoracic spine angle

KINEMATICS – Tasks

Tests of Normality (observed values)

	Classification Group	Shapiro-Wilk		
		Statistic	df	Sig.
Step Down TotLx	AEP	.930	20	.157
	FP	.982	24	.936
	Control	.966	28	.475
Step Down LLx	AEP	.915	20	.081
	FP	.921	24	.062
	Control	.980	28	.859
Step Down ULx	AEP	.976	20	.870
	FP	.966	24	.562
	Control	.981	28	.875
Step Down TotTx	AEP	.980	20	.935
	FP	.943	24	.189
	Control	.947	28	.166
Step Down LTx	AEP	.952	20	.400
	FP	.973	24	.733
	Control	.977	28	.761
Step Down UTx	AEP	.939	20	.227
	FP	.986	24	.974
	Control	.930	28	.062
Step Up TotLx	AEP	.939	20	.228
	FP	.957	24	.379
	Control	.950	28	.197
Step Up ULx	AEP	.988	20	.995
	FP	.964	24	.530
	Control	.986	28	.967
Step Up LLx	AEP	.979	20	.921
	FP	.900	24	.021
	Control	.967	28	.506
Step Up TotTx	AEP	.962	20	.583
	FP	.953	24	.307
	Control	.937	28	.092
Step Up LTx	AEP	.956	20	.469

	FP	.972	24	.713
	Control	.989	28	.987
	AEP	.964	20	.627
Step Up UTx	FP	.991	24	.998
	Control	.921	28	.037
	AEP	.956	20	.469
Reach Up TotLx	FP	.982	24	.927
	Control	.965	28	.452
	AEP	.939	20	.228
Reach Up LLx	FP	.924	24	.070
	Control	.966	28	.480
	AEP	.964	20	.636
Reach Up ULx	FP	.966	24	.570
	Control	.970	28	.576
	AEP	.937	20	.206
Reach Up TotTx	FP	.945	24	.212
	Control	.969	28	.558
	AEP	.970	20	.748
Reach Up LTx	FP	.972	24	.719
	Control	.935	28	.081
	AEP	.968	20	.716
Reach Up UTx	FP	.970	24	.662
	Control	.956	28	.272
	AEP	.956	20	.464
Stand-to-Sit TotLx	FP	.956	24	.370
	Control	.953	28	.239
	AEP	.961	20	.559
Stand-to-Sit LLx	FP	.970	24	.679
	Control	.932	28	.070
	AEP	.972	20	.797
Stand-to-Sit ULx	FP	.945	24	.211
	Control	.940	28	.108
	AEP	.955	20	.453
Stand-to-Sit TotTx	FP	.977	24	.832
	Control	.973	28	.656
Stand-to-Sit LTx	AEP	.953	20	.414

	FP	.936	24	.135
	Control	.968	28	.537
	AEP	.951	20	.388
Stand-to-Sit UTx	FP	.984	24	.951
	Control	.950	28	.194
	AEP	.985	20	.979
Sit-to-Stand TotLx	FP	.975	24	.783
	Control	.955	28	.266
	AEP	.928	20	.142
Sit-to-Stand LLx	FP	.972	24	.715
	Control	.964	28	.423
	AEP	.980	20	.936
Sit-to-Stand ULx	FP	.938	24	.150
	Control	.956	28	.272
	AEP	.949	20	.355
Sit-to-Stand TotTx	FP	.969	24	.643
	Control	.978	28	.807
	AEP	.961	20	.564
Sit-to-Stand LTx	FP	.959	24	.421
	Control	.974	28	.677
	AEP	.970	20	.763
Sit-to-Stand UTx	FP	.977	24	.824
	Control	.929	28	.057
	AEP	.952	20	.395
Box Replace TotLx	FP	.959	24	.411
	Control	.957	28	.289
	AEP	.953	20	.413
Box Replace LLx	FP	.953	24	.315
	Control	.990	28	.992
	AEP	.981	20	.949
Box Replace ULx	FP	.983	24	.943
	Control	.971	28	.603
	AEP	.971	20	.766
Box Replace TotTx	FP	.972	24	.718
	Control	.972	28	.627
Box Replace LTx	AEP	.964	20	.637

	FP	.966	24	.572
	Control	.975	28	.718
	AEP	.962	20	.593
Box Replace UTx	FP	.956	24	.357
	Control	.967	28	.491
	AEP	.969	20	.729
Box Lift TotLx	FP	.960	24	.439
	Control	.983	28	.917
	AEP	.957	20	.495
Box Lift LLx	FP	.920	24	.058
	Control	.950	28	.195
	AEP	.969	20	.739
Box Lift ULx	FP	.985	24	.969
	Control	.968	28	.528
	AEP	.949	20	.353
Box Lift TotTx	FP	.950	24	.265
	Control	.951	28	.209
	AEP	.905	20	.052
Box Lift LTx	FP	.931	24	.103
	Control	.961	28	.376
	AEP	.935	20	.196
Box Lift UTx	FP	.950	24	.276
	Control	.945	28	.151
	AEP	.957	20	.489
Bend to pick up pen TotLx	FP	.959	24	.426
	Control	.901	28	.012
	AEP	.975	20	.850
Bend to pick up pen LLx	FP	.963	24	.512
	Control	.940	28	.109
	AEP	.957	20	.478
Bend to pick up pen ULx	FP	.944	24	.197
	Control	.933	28	.073
	AEP	.973	20	.814
Bend to pick up pen TotTx	FP	.958	24	.394
	Control	.970	28	.574
Bend to pick up pen LTx	AEP	.981	20	.944

	FP	.946	24	.219
	Control	.987	28	.968
	AEP	.946	20	.313
Bend to pick up pen UTx	FP	.976	24	.814
	Control	.915	28	.026
	AEP	.934	20	.185
Return from pick up pen TotLx	FP	.963	24	.499
	Control	.954	28	.253
	AEP	.971	20	.779
Return from pick up pen LLx	FP	.969	24	.644
	Control	.949	28	.184
	AEP	.980	20	.932
Return from pick up pen ULx	FP	.957	24	.373
	Control	.946	28	.160
	AEP	.958	20	.497
Return from pick up pen TotTx	FP	.925	24	.076
	Control	.977	28	.771
	AEP	.987	20	.990
Return from pick up pen LTx	FP	.929	24	.092
	Control	.967	28	.507
	AEP	.942	20	.263
Return from pick up pen UTx	FP	.964	24	.513
	Control	.955	28	.259

Key: TotLx = total lumbar spine angle; LLx = lower lumbar spine angle; ULx = upper lumbar spine angle; TotTx = total thoracic spine angle; LTx = lower thoracic spine angle; UTx = upper thoracic spine angle; AEP = Active Extension Pattern; FP = Flexion Pattern

Tests of Homogeneity of Variance (observed values)

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Step Down TotLx	2.664	2	75	.076
Step Down LLx	2.409	2	75	.097
Step Down ULx	.783	2	75	.461
Step Down TotTx	.916	2	75	.404
Step Down LTx	1.259	2	75	.290
Step Down UTx	.027	2	75	.974
Step Up TotLx	1.900	2	75	.157
Step Up ULx	1.625	2	75	.204
Step Up LLx	3.365	2	75	.040
Step Up TotTx	1.157	2	75	.320
Step Up LTx	1.084	2	75	.343
Step Up UTx	.022	2	75	.978
Reach Up TotLx	3.094	2	75	.051
Reach Up LLx	.554	2	75	.577
Reach Up ULx	1.120	2	75	.332
Reach Up TotTx	.283	2	75	.754
Reach Up LTx	.645	2	75	.528
Reach Up UTx	.003	2	75	.997
Stand-to-Sit TotLx	1.538	2	74	.222
Stand-to-Sit LLx	1.307	2	74	.277
Stand-to-Sit ULx	.592	2	74	.556
Stand-to-Sit TotTx	.322	2	74	.726
Stand-to-Sit LTx	.316	2	74	.730
Stand-to-Sit UTx	.218	2	74	.805
Sit-to-Stand TotLx	2.287	2	74	.109
Sit-to-Stand LLx	1.541	2	74	.221
Sit-to-Stand ULx	.254	2	74	.776
Sit-to-Stand TotTx	.056	2	74	.945
Sit-to-Stand LTx	.470	2	74	.627
Sit-to-Stand UTx	.359	2	74	.699
Box Replace TotLx	1.623	2	74	.204
Box Replace LLx	1.766	2	74	.178
Box Replace ULx	1.392	2	74	.255
Box Replace TotTx	.566	2	74	.570
Box Replace LTx	1.563	2	74	.216
Box Replace UTx	.019	2	74	.981
Box Lift TotLx	1.484	2	74	.233
Box Lift LLx	3.446	2	74	.037
Box Lift ULx	1.579	2	74	.213
Box Lift TotTx	1.092	2	74	.341

Box Lift LTx	.416	2	74	.661
Box Lift UTx	.495	2	74	.612
Bend to pick up pen TotLx	3.858	2	73	.026
Bend to pick up pen LLx	1.799	2	72	.173
Bend to pick up pen ULx	.384	2	71	.683
Bend to pick up pen TotTx	1.287	2	73	.282
Bend to pick up pen LTx	1.570	2	73	.215
Bend to pick up pen UTx	.176	2	73	.839
Return from pick up pen TotLx	3.306	2	73	.042
Return from pick up pen LLx	1.329	2	72	.271
Return from pick up pen ULx	.673	2	71	.513
Return from pick up pen TotTx	1.480	2	73	.234
Return from pick up pen LTx	1.248	2	73	.293
Return from pick up pen UTx	.504	2	73	.606

Key: TotLx = total lumbar spine angle; LLx = lower lumbar spine angle; ULx = upper lumbar spine angle; TotTx = total thoracic spine angle; LTx = lower thoracic spine angle; UTx = upper thoracic spine angle

SURFACE ELECTROMYOGRAPHY – Tasks

Tests of Normality (observed values)

	Classification Group	Shapiro-Wilk		
		Statistic	df	Sig.
Step Down Left IO	AEP	0.755	8	0.009
	FP	0.928	12	0.364
	Control	0.941	10	0.569
Step Down Right IO	AEP	0.904	8	0.315
	FP	0.911	12	0.221
	Control	0.851	10	0.060
Step Down Left EO	AEP	0.793	8	0.024
	FP	0.920	12	0.287
	Control	0.946	10	0.619
Step Down Right EO	AEP	0.804	8	0.032
	FP	0.941	12	0.515
	Control	0.974	10	0.924
Step Down Left LM	AEP	0.711	8	0.003
	FP	0.718	12	0.001
	Control	0.918	10	0.344
Step Down Right LM	AEP	0.785	8	0.020
	FP	0.794	12	0.008
	Control	0.921	10	0.364
Step Down Left LT	AEP	0.849	8	0.094
	FP	0.690	12	0.001
	Control	0.964	10	0.834
Step Down Right LT	AEP	0.853	8	0.103
	FP	0.700	12	0.001
	Control	0.705	10	0.001
Step Up Left IO	AEP	0.803	8	0.031
	FP	0.919	12	0.275
	Control	0.938	10	0.526
Step Up Right IO	AEP	0.943	8	0.644
	FP	0.908	12	0.202
	Control	0.850	10	0.058
Step Up Left EO	AEP	0.855	8	0.107
	FP	0.929	12	0.369
	Control	0.950	10	0.664
Step Up Right EO	AEP	0.822	8	0.049
	FP	0.943	12	0.534
	Control	0.941	10	0.559
Step Up Left LM	AEP	0.687	8	0.002
	FP	0.706	12	0.001
	Control	0.903	10	0.234
Step Up Right LM	AEP	0.819	8	0.045

	FP	0.762	12	0.004
	Control	0.919	10	0.350
	AEP	0.959	8	0.796
Step Up Left LT	FP	0.734	12	0.002
	Control	0.914	10	0.307
	AEP	0.912	8	0.368
Step Up Right LT	FP	0.667	12	0.000
	Control	0.781	10	0.009
	AEP	0.934	8	0.551
Reach Up Left IO	FP	0.836	12	0.025
	Control	0.759	10	0.005
	AEP	0.872	8	0.157
Reach Up Right IO	FP	0.907	12	0.193
	Control	0.811	10	0.020
	AEP	0.773	8	0.015
Reach Up Left EO	FP	0.916	12	0.256
	Control	0.943	10	0.583
	AEP	0.884	8	0.204
Reach Up Right EO	FP	0.935	12	0.442
	Control	0.941	10	0.567
	AEP	0.753	8	0.009
Reach Up Left LM	FP	0.611	12	0.000
	Control	0.853	10	0.063
	AEP	0.799	8	0.028
Reach Up Right LM	FP	0.621	12	0.000
	Control	0.910	10	0.282
	AEP	0.871	8	0.154
Reach Up Left LT	FP	0.727	12	0.002
	Control	0.882	10	0.139
	AEP	0.953	8	0.736
Reach Up Right LT	FP	0.696	12	0.001
	Control	0.885	10	0.147
	AEP	0.868	8	0.146
Bend to pick up pen Left IO	FP	0.932	12	0.404
	Control	0.900	10	0.220
	AEP	0.919	8	0.425
Bend to pick up pen Right IO	FP	0.943	12	0.543
	Control	0.878	10	0.125
	AEP	0.882	8	0.195
Bend to pick up pen Left EO	FP	0.940	12	0.496
	Control	0.905	10	0.247
	AEP	0.924	8	0.460
Bend to pick up pen Right EO	FP	0.891	12	0.123
	Control	0.919	10	0.351
	AEP	0.495	8	0.000
Bend to pick up pen Left LM	FP	0.627	12	0.000

	Control	0.902	10	0.233
	AEP	0.780	8	0.018
Bend to pick up pen Right LM	FP	0.630	12	0.000
	Control	0.954	10	0.718
	AEP	0.592	8	0.000
Bend to pick up pen Left LT	FP	0.759	12	0.003
	Control	0.931	10	0.453
	AEP	0.939	8	0.605
Bend to pick up pen Right LT	FP	0.617	12	0.000
	Control	0.749	10	0.003
	AEP	0.817	8	0.044
Return from pick up pen Left IO	FP	0.929	12	0.369
	Control	0.939	10	0.545
	AEP	0.902	8	0.300
Return from pick up pen Right IO	FP	0.947	12	0.588
	Control	0.879	10	0.128
	AEP	0.916	8	0.395
Return from pick up pen Left EO	FP	0.926	12	0.344
	Control	0.942	10	0.574
	AEP	0.910	8	0.354
Return from pick up pen Right EO	FP	0.892	12	0.124
	Control	0.917	10	0.330
	AEP	0.483	8	0.000
Return from pick up pen Left LM	FP	0.579	12	0.000
	Control	0.912	10	0.293
	AEP	0.780	8	0.017
Return from pick up pen Right LM	FP	0.649	12	0.000
	Control	0.923	10	0.386
	AEP	0.582	8	0.000
Return from pick up pen Left LT	FP	0.745	12	0.002
	Control	0.978	10	0.954
	AEP	0.955	8	0.756
Return from pick up pen Right LT	FP	0.678	12	0.001
	Control	0.683	10	0.001
	AEP	0.870	8	0.149
Stand-to-Sit Left IO	FP	0.860	12	0.049
	Control	0.939	10	0.537
	AEP	0.965	8	0.857
Stand-to-Sit Right IO	FP	0.811	12	0.013
	Control	0.866	10	0.090
	AEP	0.951	8	0.720
Stand-to-Sit Left EO	FP	0.924	12	0.317
	Control	0.951	10	0.685
	AEP	0.889	8	0.227
Stand-to-Sit Right EO	FP	0.935	12	0.437
	Control	0.936	10	0.507

	AEP	0.871	8	0.154
Stand-to-Sit Left LM	FP	0.849	12	0.035
	Control	0.898	10	0.208
	AEP	0.876	8	0.172
Stand-to-Sit Right LM	FP	0.896	12	0.142
	Control	0.943	10	0.591
	AEP	0.849	8	0.093
Stand-to-Sit Left LT	FP	0.870	12	0.065
	Control	0.943	10	0.589
	AEP	0.941	8	0.625
Stand-to-Sit Right LT	FP	0.882	12	0.094
	Control	0.850	10	0.059
	AEP	0.814	8	0.041
Sit-to-Stand Left IO	FP	0.714	12	0.001
	Control	0.940	10	0.554
	AEP	0.969	8	0.888
Sit-to-Stand Right IO	FP	0.892	12	0.123
	Control	0.876	10	0.118
	AEP	0.882	8	0.198
Sit-to-Stand Left EO	FP	0.908	12	0.198
	Control	0.958	10	0.761
	AEP	0.909	8	0.350
Sit-to-Stand Right EO	FP	0.910	12	0.211
	Control	0.910	10	0.282
	AEP	0.688	8	0.002
Sit-to-Stand Left LM	FP	0.736	12	0.002
	Control	0.903	10	0.234
	AEP	0.745	8	0.007
Sit-to-Stand Right LM	FP	0.763	12	0.004
	Control	0.914	10	0.311
	AEP	0.925	8	0.469
Sit-to-Stand Left LT	FP	0.698	12	0.001
	Control	0.925	10	0.403
	AEP	0.929	8	0.506
Sit-to-Stand Right LT	FP	0.787	12	0.007
	Control	0.822	10	0.027
	AEP	0.898	8	0.277
Box Replace Left IO	FP	0.903	12	0.173
	Control	0.641	10	0.000
	AEP	0.933	8	0.540
Box Replace Right IO	FP	0.894	12	0.132
	Control	0.810	10	0.019
	AEP	0.765	8	0.012
Box Replace Left EO	FP	0.908	12	0.200
	Control	0.939	10	0.546
Box Replace Right EO	AEP	0.853	8	0.101

	FP	0.900	12	0.158
	Control	0.958	10	0.762
	AEP	0.758	8	0.010
Box Replace Left LM	FP	0.677	12	0.001
	Control	0.892	10	0.177
	AEP	0.909	8	0.349
Box Replace Right LM	FP	0.758	12	0.003
	Control	0.917	10	0.333
	AEP	0.906	8	0.325
Box Replace Left LT	FP	0.733	12	0.002
	Control	0.894	10	0.189
	AEP	0.953	8	0.737
Box Replace Right LT	FP	0.680	12	0.001
	Control	0.935	10	0.495
	AEP	0.868	8	0.144
Box Lift Left IO	FP	0.893	12	0.129
	Control	0.727	10	0.002
	AEP	0.924	8	0.465
Box Lift Right IO	FP	0.904	12	0.180
	Control	0.809	10	0.019
	AEP	0.775	8	0.015
Box Lift Left EO	FP	0.929	12	0.372
	Control	0.979	10	0.959
	AEP	0.828	8	0.056
Box Lift Right EO	FP	0.941	12	0.517
	Control	0.970	10	0.891
	AEP	0.788	8	0.021
Box Lift Left LM	FP	0.694	12	0.001
	Control	0.907	10	0.259
	AEP	0.872	8	0.156
Box Lift Right LM	FP	0.761	12	0.003
	Control	0.926	10	0.413
	AEP	0.881	8	0.192
Box Lift Left LT	FP	0.743	12	0.002
	Control	0.935	10	0.495
	AEP	0.875	8	0.167
Box Lift Right LT	FP	0.726	12	0.002
	Control	0.652	10	0.000

Key: IO = Transversus Abdominis / Internal Oblique, EO = External Oblique, LM = superficial Lumbar Multifidus, LT = Longissimus Thoracis (Erector Spinae)

Tests of Homogeneity of Variance (observed values)

	Levene Statistic	df1	df2	Sig.
Step Down Left IO	0.625	2	27	0.543
Step Down Right IO	0.914	2	27	0.413
Step Down Left EO	2.467	2	27	0.104
Step Down Right EO	0.256	2	27	0.776
Step Down Left LM	0.924	2	27	0.409
Step Down Right LM	2.097	2	27	0.142
Step Down Left LT	1.087	2	27	0.351
Step Down Right LT	2.671	2	27	0.087
Step Up Left IO	0.604	2	27	0.554
Step Up Right IO	0.895	2	27	0.421
Step Up Left EO	2.445	2	27	0.106
Step Up Right EO	0.757	2	27	0.479
Step Up Left LM	1.226	2	27	0.309
Step Up Right LM	3.452	2	27	0.046
Step Up Left LT	1.041	2	27	0.367
Step Up Right LT	3.452	2	27	0.046
Reach Up Left IO	0.319	2	27	0.729
Reach Up Right IO	0.861	2	27	0.434
Reach Up Left EO	2.693	2	27	0.086
Reach Up Right EO	0.800	2	27	0.460
Reach Up Left LM	0.700	2	27	0.505
Reach Up Right LM	1.491	2	27	0.243
Reach Up Left LT	1.736	2	27	0.195
Reach Up Right LT	3.296	2	27	0.052
Bend to pick up pen Left IO	1.032	2	27	0.370
Bend to pick up pen Right IO	1.236	2	27	0.306
Bend to pick up pen Left EO	2.687	2	27	0.086
Bend to pick up pen Right EO	1.090	2	27	0.351
Bend to pick up pen Left LM	3.205	2	27	0.056
Bend to pick up pen Right LM	2.119	2	27	0.140
Bend to pick up pen Left LT	3.050	2	27	0.064
Bend to pick up pen Right LT	3.077	2	27	0.063
Return from pick up pen Left IO	1.043	2	27	0.366
Return from pick up pen Right IO	1.293	2	27	0.291
Return from pick up pen Left EO	3.893	2	27	0.033
Return from pick up pen Right EO	1.642	2	27	0.212
Return from pick up pen Left LM	3.122	2	27	0.060
Return from pick up pen Right LM	1.895	2	27	0.170
Return from pick up pen Left LT	2.759	2	27	0.081
Return from pick up pen Right LT	3.301	2	27	0.052
Stand-to-Sit Left IO	5.001	2	27	0.014
Stand-to-Sit Right IO	2.937	2	27	0.070

Stand-to-Sit Left EO	1.660	2	27	0.209
Stand-to-Sit Right EO	1.300	2	27	0.289
Stand-to-Sit Left LM	3.147	2	27	0.059
Stand-to-Sit Right LM	5.214	2	27	0.012
Stand-to-Sit Left LT	5.121	2	27	0.013
Stand-to-Sit Right LT	3.097	2	27	0.062
Sit-to-Stand Left IO	1.664	2	27	0.208
Sit-to-Stand Right IO	1.808	2	27	0.183
Sit-to-Stand Left EO	1.165	2	27	0.327
Sit-to-Stand Right EO	0.880	2	27	0.426
Sit-to-Stand Left LM	3.322	2	27	0.051
Sit-to-Stand Right LM	4.034	2	27	0.029
Sit-to-Stand Left LT	1.100	2	27	0.347
Sit-to-Stand Right LT	4.693	2	27	0.018
Box Replace Left IO	0.474	2	27	0.628
Box Replace Right IO	2.760	2	27	0.081
Box Replace Left EO	1.558	2	27	0.229
Box Replace Right EO	0.472	2	27	0.629
Box Replace Left LM	0.620	2	27	0.545
Box Replace Right LM	1.795	2	27	0.185
Box Replace Left LT	1.916	2	27	0.167
Box Replace Right LT	2.297	2	27	0.120
Box Lift Left IO	0.504	2	27	0.610
Box Lift Right IO	1.860	2	27	0.175
Box Lift Left EO	2.061	2	27	0.147
Box Lift Right EO	0.268	2	27	0.767
Box Lift Left LM	0.585	2	27	0.564
Box Lift Right LM	1.735	2	27	0.196
Box Lift Left LT	1.350	2	27	0.276
Box Lift Right LT	4.176	2	27	0.026

Key: IO = Transversus Abdominis / Internal Oblique, EO = External Oblique, LM = superficial Lumbar Multifidus, LT = Longissimus Thoracis (Erector Spinae)

APPENDIX IX

Electromyography T-tests

T-tests for Left and Right Musculature

Ascertaining whether differences exist in the right and left musculature
(mean muscle amplitude)

In order to establish whether the right and left musculature should be considered as a single averaged value, only one side reported or if both sides needed to be evaluated independently paired t-tests were undertaken on the sEMG data from each muscle pair (left and right) during each task. The results are presented in the table below. A number of significant differences (*p<0.05) were identified between sides. Therefore both sides were considered and analysed independently for final analysis.

Results of the paired t-tests for the left and right sEMG mean amplitudes (%SMVC) of the investigated musculature during the functional tasks (*p<0.05)

Task	Muscle	Side	Mean (SD)	t	Significance
Step Down	TrAIO	Left	77.8 (48.3)	4.324	0.000*
		Right	57.3 (33.0)		
	EO	Left	54.7 (29.1)	2.867	0.006*
		Right	47.6 (22.3)		
	LM	Left	17.7 (14.6)	-2.432	0.018*
		Right	23.7 (23.8)		
	LT	Left	22.9 (13.7)	-0.475	0.636
		Right	23.5 (13.9)		
Step Up	TrAIO	Left	78.5 (52.9)	3.924	0.000*
		Right	56.9 (34.9)		
	EO	Left	53.7 (27.0)	3.049	0.003*
		Right	47.4 (22.8)		
	LM	Left	17.5 (15.4)	-2.422	0.018*
		Right	23.4 (25.3)		
	LT	Left	22.6 (13.7)	-0.280	0.781
		Right	23.0 (14.3)		
Reach Up	TrAIO	Left	67.0 (49.1)	2.584	0.012*
		Right	55.3 (33.5)		
	EO	Left	50.5 (26.4)	2.806	0.007*
		Right	44.4 (20.7)		
	LM	Left	16.9 (14.4)	-0.866	0.390
		Right	18.8 (20.5)		
	LT	Left	23.7 (16.3)	2.257	0.028*

		Right	20.7 (12.9)		
Bend to pick up pen	TrAIO	Left	90.4 (95.2)	3.205	0.002*
		Right	55.6 (35.0)		
	EO	Left	52.5 (29.2)	3.446	0.001*
		Right	44.3 (22.8)		
	LM	Left	19.3 (23.8)	-1.063	0.292
		Right	30.3 (83.3)		
	LT	Left	23.4 (22.0)	0.729	0.469
		Right	21.7 (14.3)		
Return from picking up pen	TrAIO	Left	85.7 (91.4)	2.970	0.004*
		Right	54.1 (34.1)		
	EO	Left	52.9 (29.0)	3.775	0.000*
		Right	44.1 (23.2)		
	LM	Left	19.0 (23.5)	-1.141	0.258
		Right	31.7 (89.5)		
	LT	Left	23.4 (21.8)	0.725	0.472
		Right	21.8 (13.8)		
Stand-to-Sit	TrAIO	Left	56.3 (41.6)	0.515	0.609
		Right	53.9 (45.1)		
	EO	Left	52.0 (27.9)	3.068	0.003*
		Right	45.6 (22.1)		
	LM	Left	25.4 (18.6)	-1.211	0.231
		Right	31.7 (42.7)		
	LT	Left	38.8 (28.3)	2.632	0.011*
		Right	32.5 (19.6)		
Sit-to-Stand	TrAIO	Left	50.0 (36.4)	0.174	0.862
		Right	49.2 (39.4)		
	EO	Left	49.3 (24.7)	2.926	0.005*
		Right	44.1 (21.5)		
	LM	Left	16.6 (14.9)	-1.630	0.109
		Right	26.1 (47.3)		
	LT	Left	26.7 (18.6)	2.007	0.049*
		Right	23.4 (12.4)		
Box Replace	TrAIO	Left	73.6 (50.1)	3.101	0.003*
		Right	58.6 (38.8)		

	EO	Left	52.5 (26.2)	2.862	0.006*
		Right	46.1 (21.9)		
	LM	Left	19.0 (14.4)	-1.912	0.060
		Right	23.2 (20.3)		
	LT	Left	22.6 (15.0)	-1.067	0.290
		Right	24.0 (14.3)		
Box Lift	TrAIO	Left	74.3 (49.0)	3.217	0.002*
		Right	59.1 (39.4)		
	EO	Left	53.5 (27.4)	3.035	0.004*
		Right	46.2 (21.3)		
	LM	Left	18.9 (14.0)	-2.466	0.016*
		Right	24.3 (20.7)		
	LT	Left	22.5 (14.3)	-1.705	0.094
		Right	24.7 (13.4)		

Key: TrAIO = Transversus Abdominis; EO = External Oblique; LM = Lumbar multifidus; LT = Longissimus Thoracis (Erector Spinae); SD = standard deviation; t= t-value (t-test score)